Photonic lanterns: flexible, efficient, and affordable radiators for novel diagnostics at picosecond resolution

15th International Beam Instrumentation Conference, 2026, Whistler BC, Canada

P. Pushkarna

R. Dowd, S. Leon-Saval, P. J. Giansiracusa, V. Lu, R. P. Rassool, S. L. Sheehy, Y-R. E. Tan, G. N. Taylor, J. Valerian, M. Volpi, J. Wei

Measuring longitudinal profiles with a photonic lantern

Problem statement
Why *non-scintillating* optical fibers?
Why photonic lanterns?

What do photonic lanterns do?

Results
How do lanterns compare with fibers?

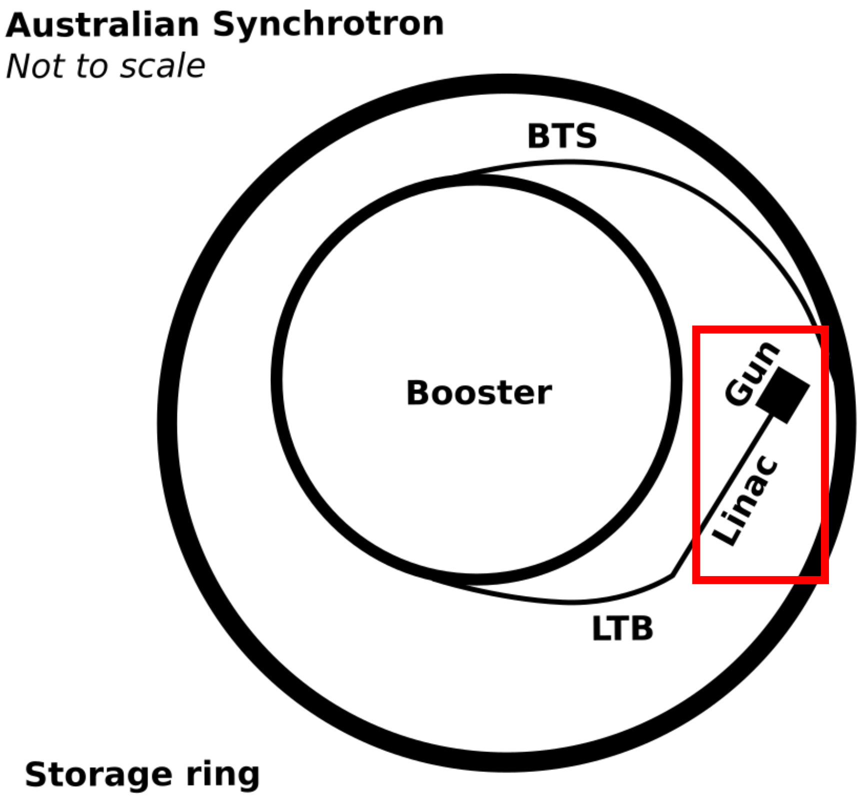
What next?

Radiative diagnostics: using light as a yardstick

Generation | **Transport** | **Detection**

Radiative diagnostics: using light as a yardstick

Generation

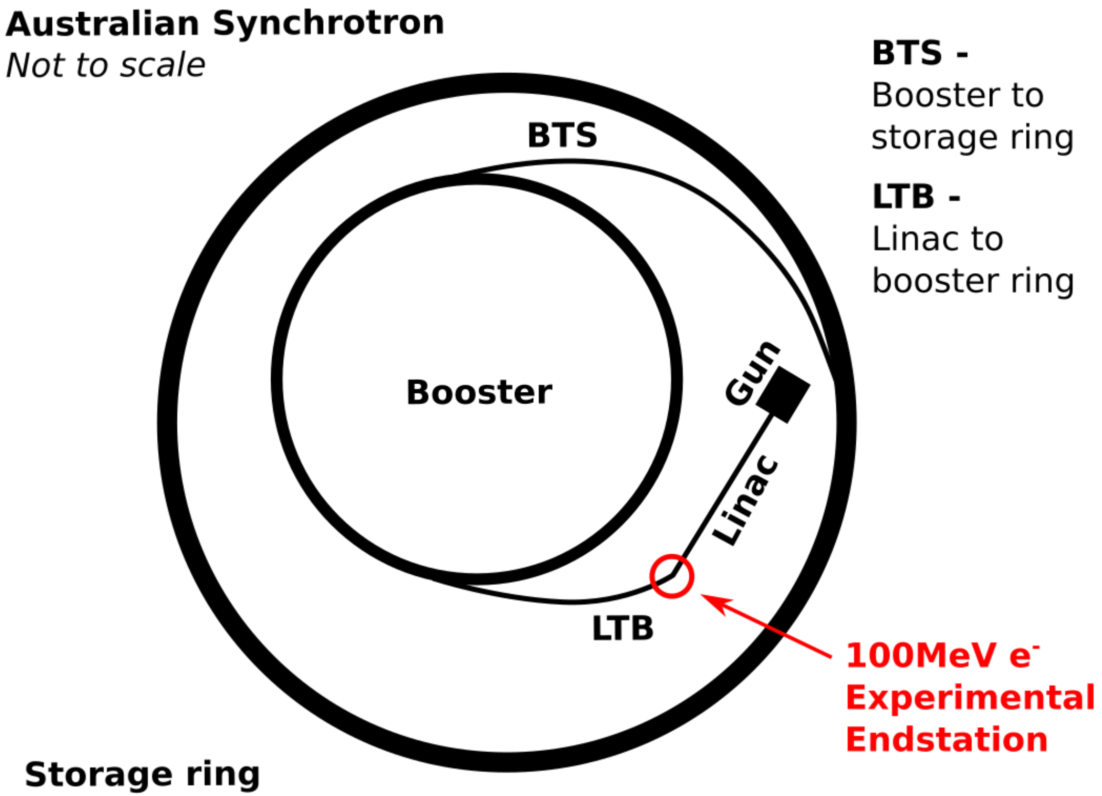


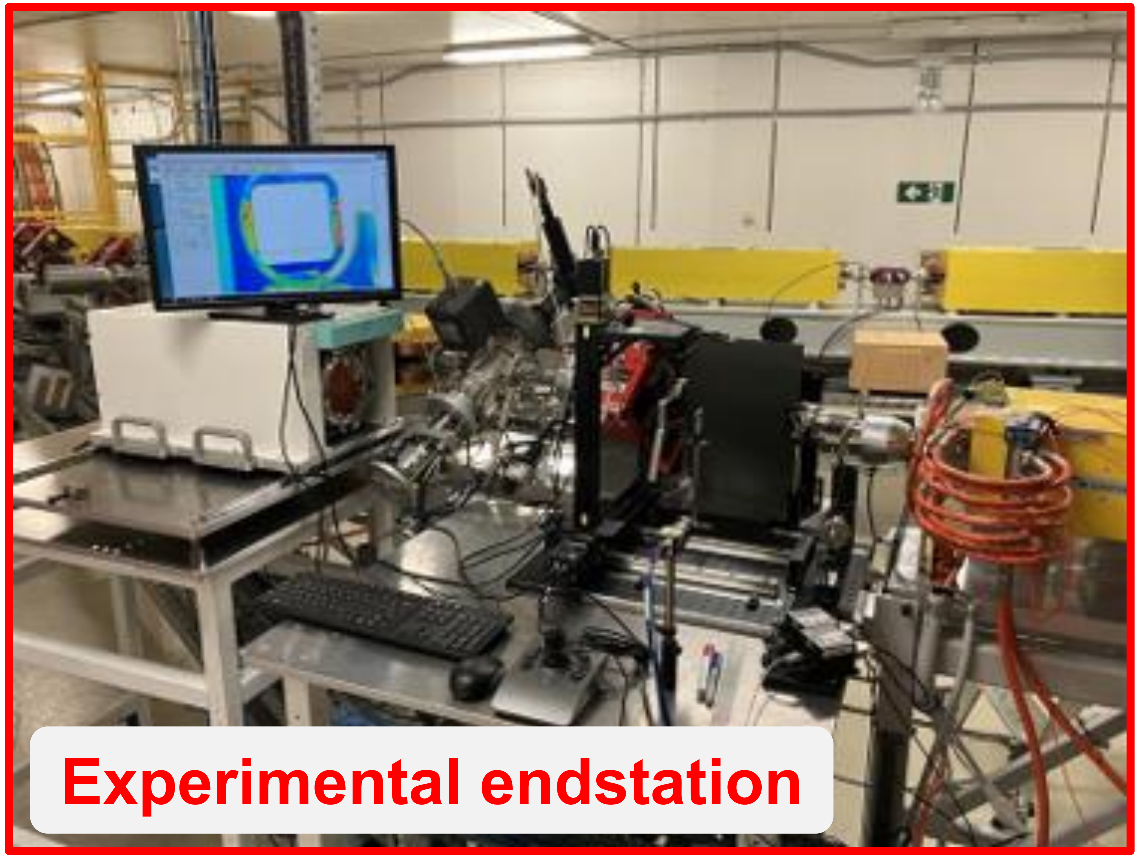
BTS - Booster to storage ring

LTB - Linac to booster ring

Radiative diagnostics: using light as our yardstick

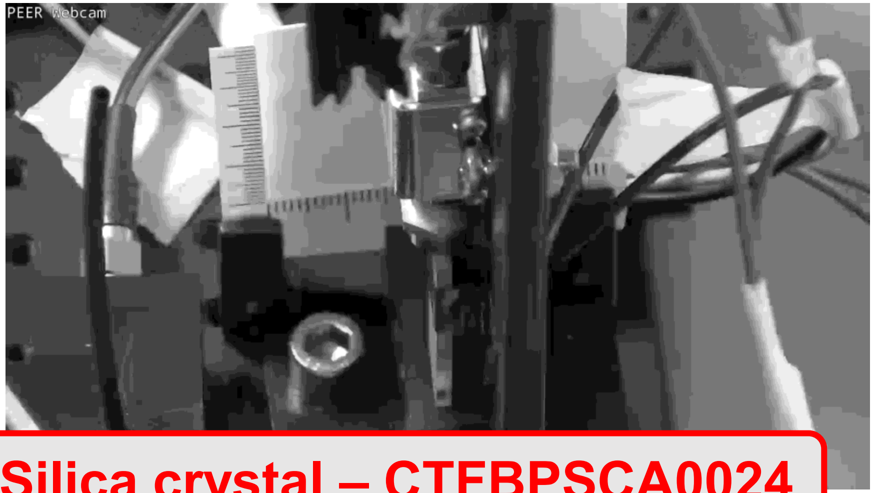
Generation





Radiative diagnostics: using light as a yardstick

Generation



Silica crystal – CTFBPSCA0024

Transport

In-air, free space:
1. Lenses
2. Mirrors
3. Culverts

Detection

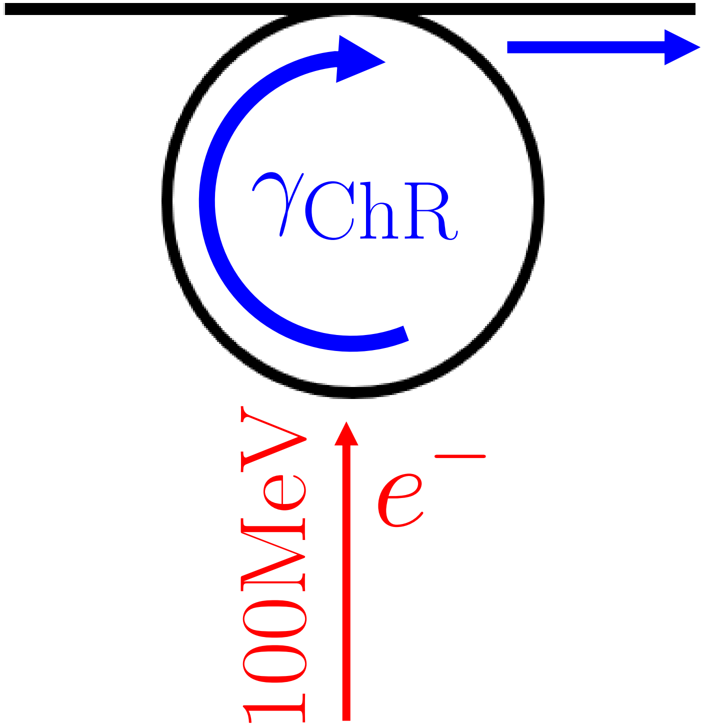
Streak Camera

Combining generation and transport

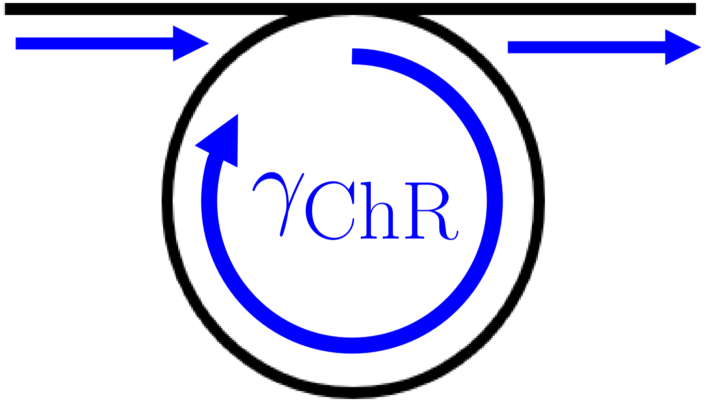
Generation + **Transport**

Detection

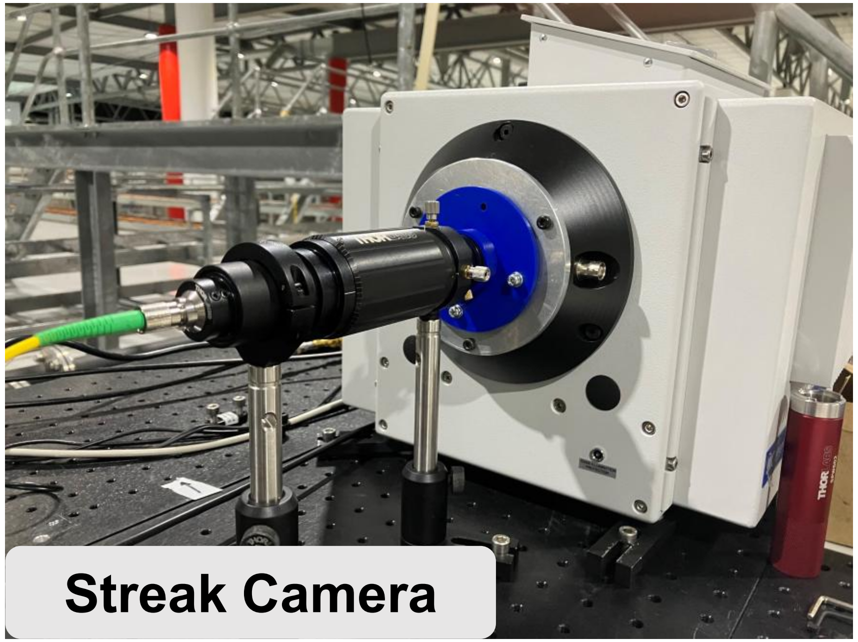
15m 105µm 0.10 NA Fiber



15m 105µm 0.10 NA Fiber



Transport occurs in the ***SAME fiber***



Streak Camera

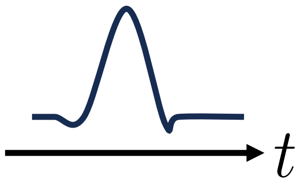
Intensity vs. dispersion trade-off

Generation + **Transport**

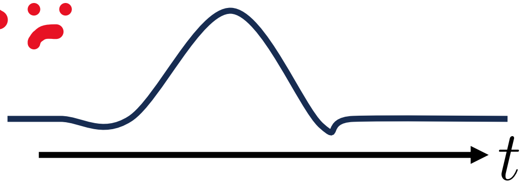
Detection

Multimode fibers (MMFs)

Higher ChR intensity

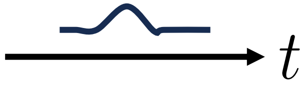


Dispersive transport

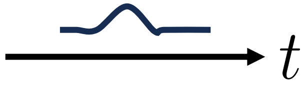


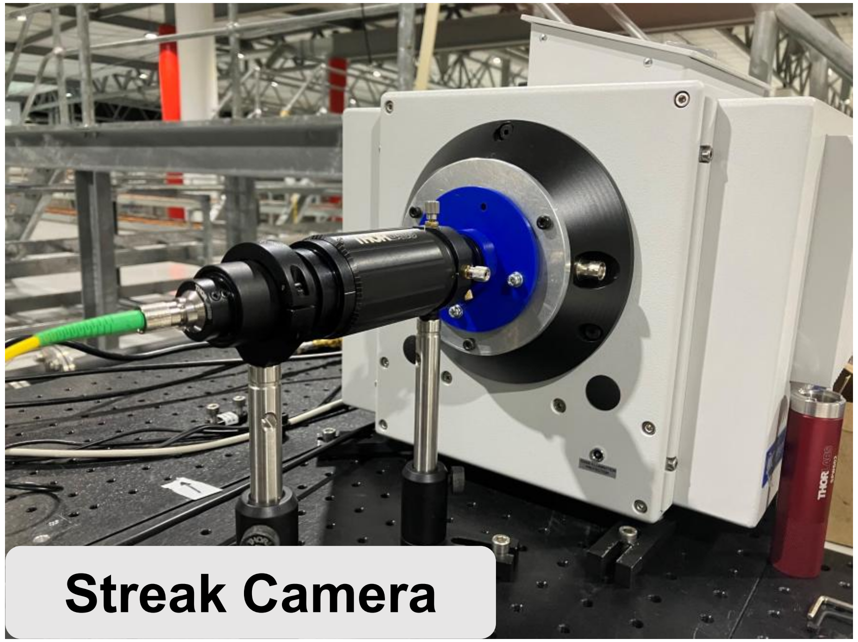
Single mode fibers (SMFs)

Poorer ChR intensity



Few-moded transport



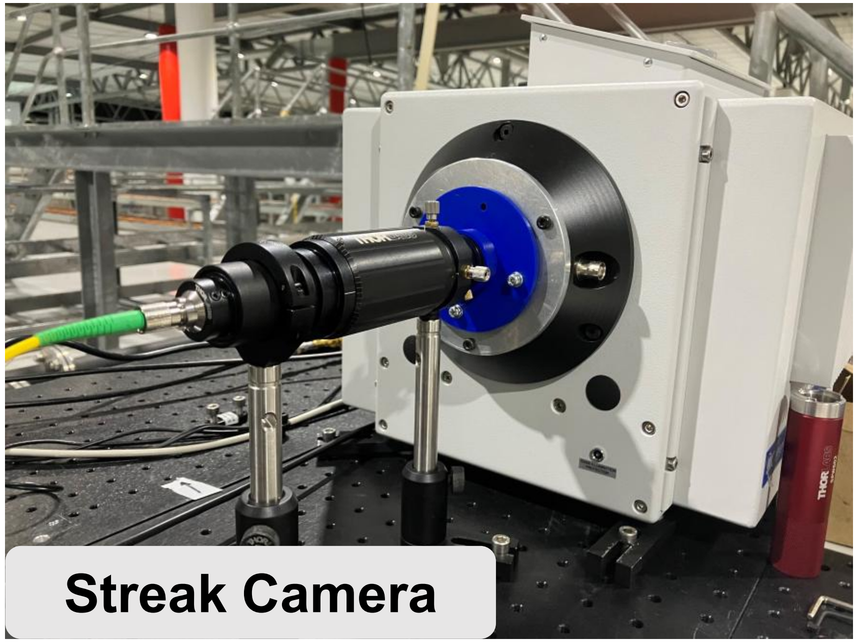


Streak Camera

The best of both worlds?

Generation + **Transport**

Detection



Multimode fibers (MMFs)

Higher ChR intensity

Single mode fibers (SMFs)

Few-moded transport

The best of both worlds? Photonic lanterns

Generation + **Transport**

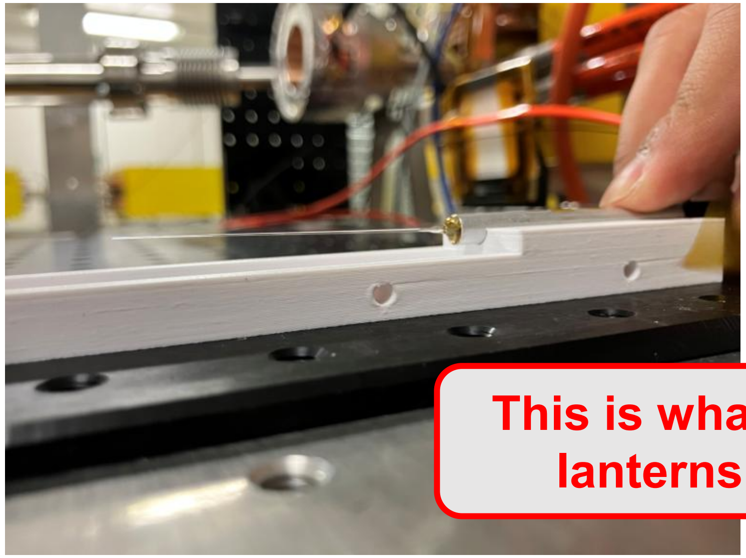
Detection

Multimode fibers (MMFs)

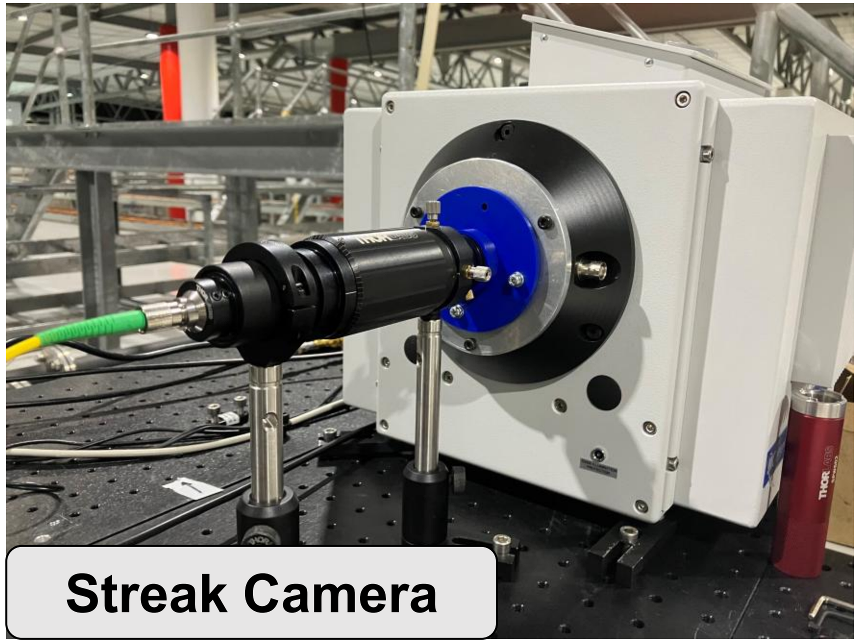
Higher ChR intensity

Single mode fibers (SMFs)

Few-moded transport

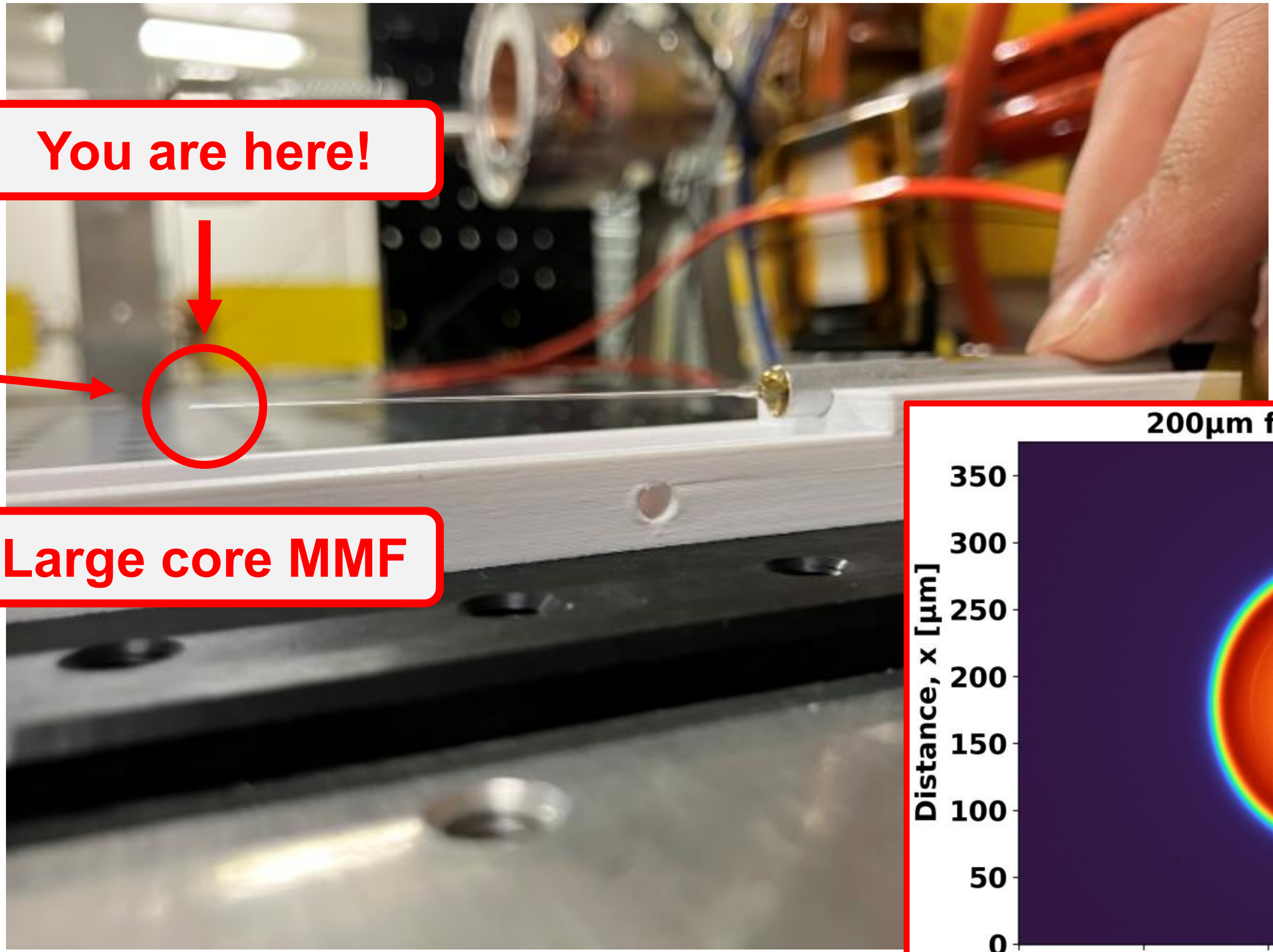


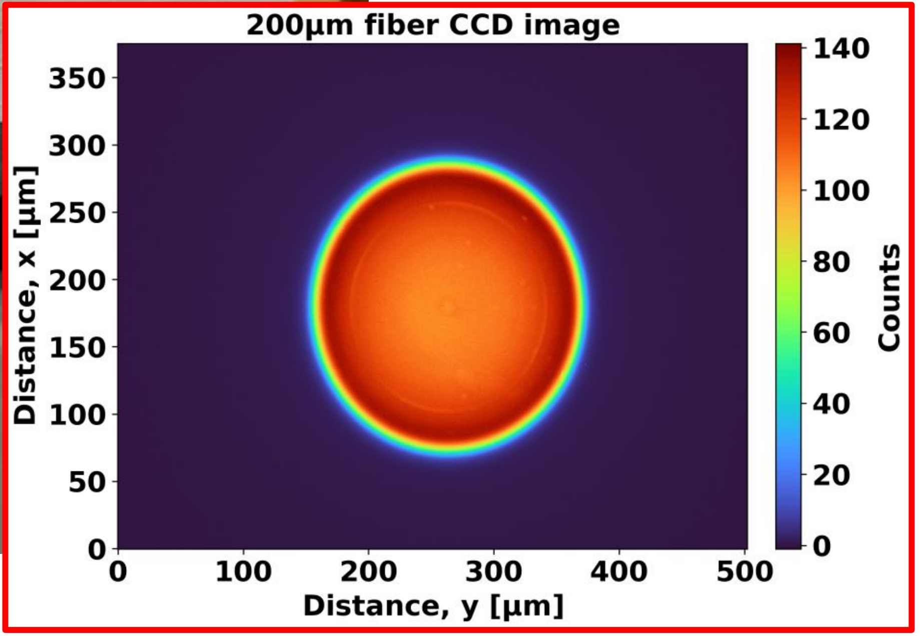
This is what Photonic lanterns are for!



Streak Camera

How do photonic lanterns work?



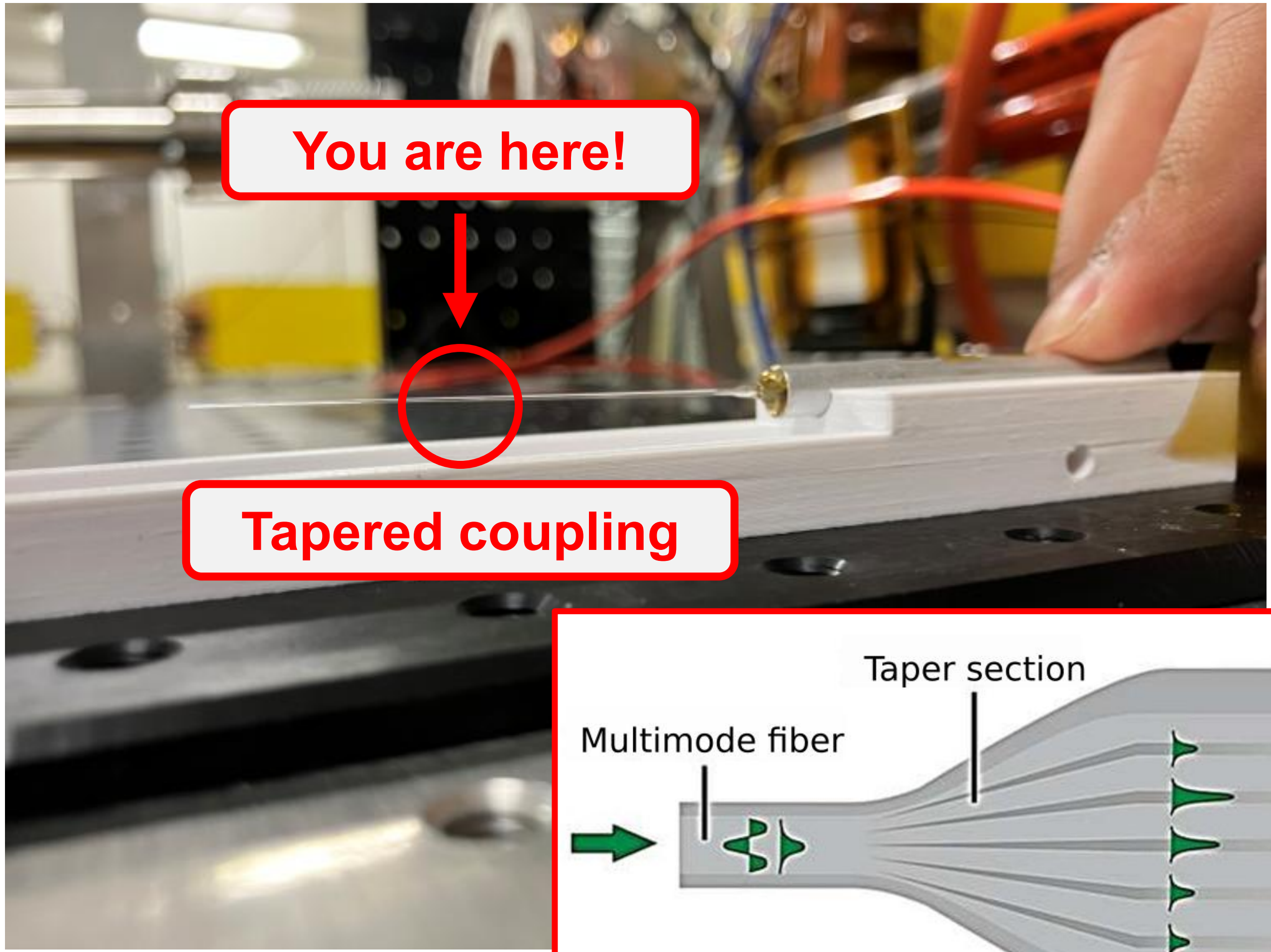


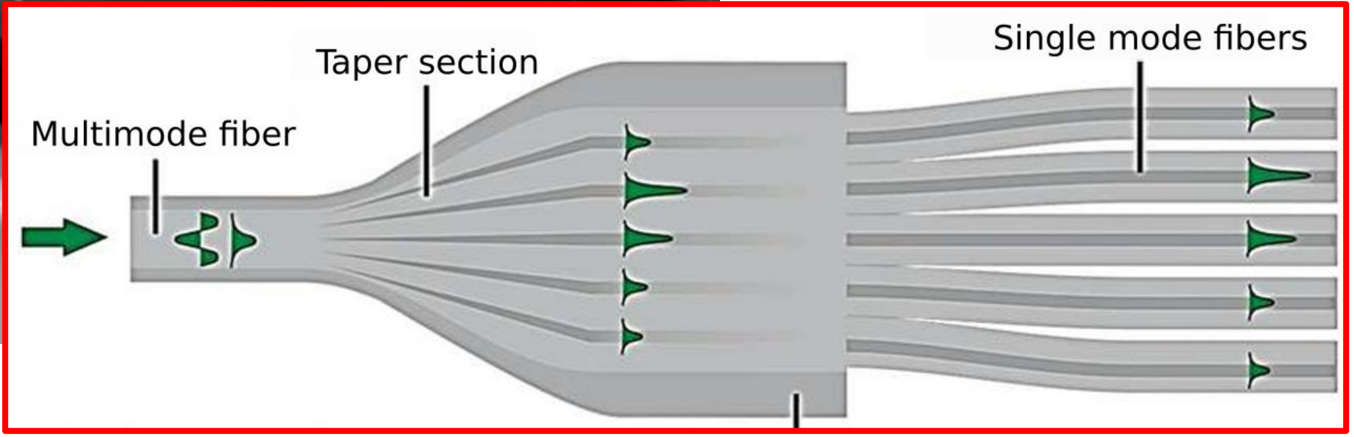
Fabricated by:

THE UNIVERSITY OF SYDNEY

SAIL
SYDNEY ASTROPHOTONIC INSTRUMENTATION LABORATORY

How do photonic lanterns work?



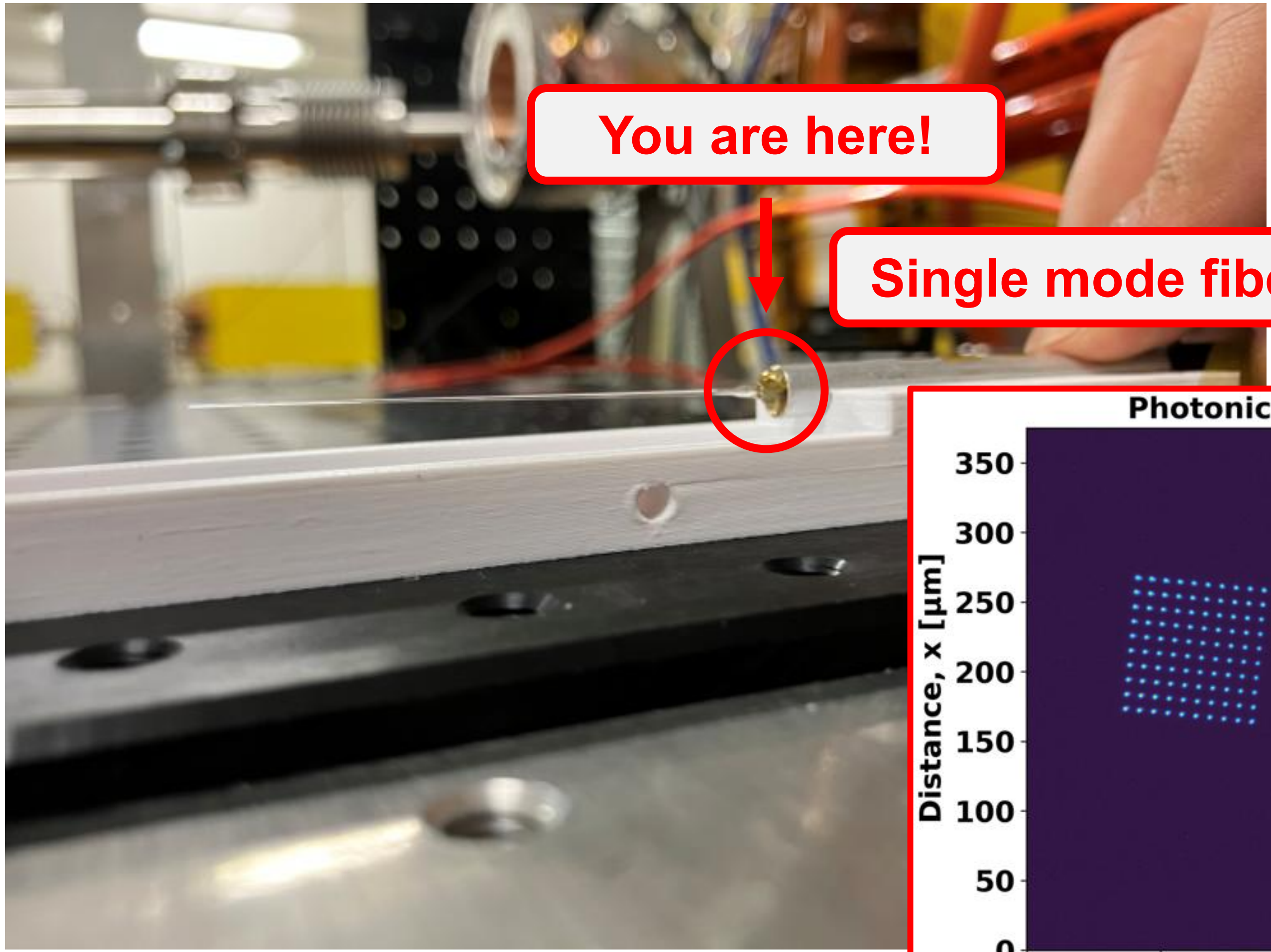


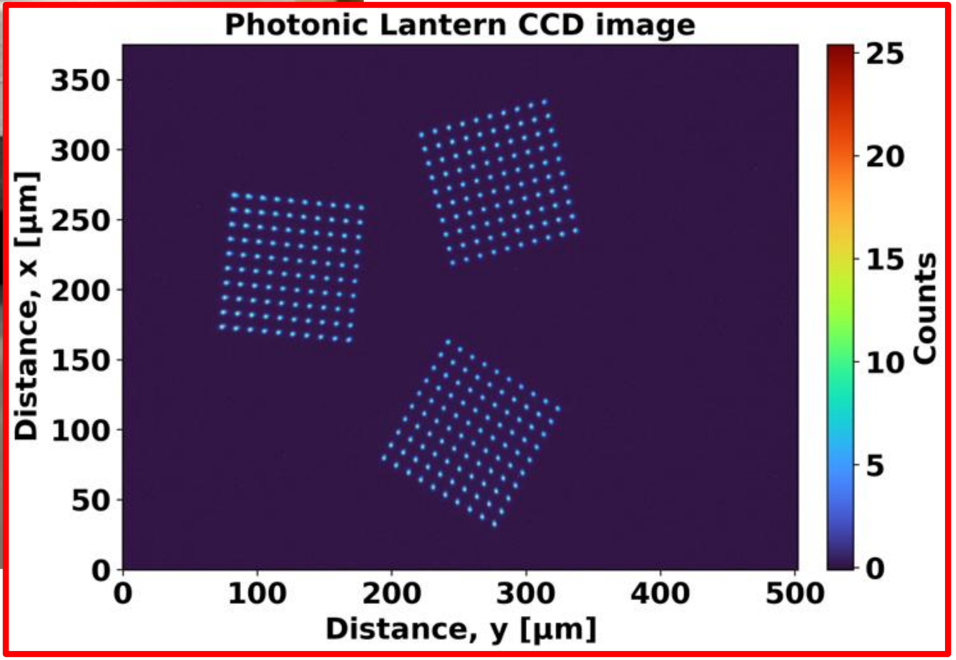
Fabricated by:

THE UNIVERSITY OF SYDNEY

SAIL
SYDNEY ASTROPHOTONIC INSTRUMENTATION LABORATORY

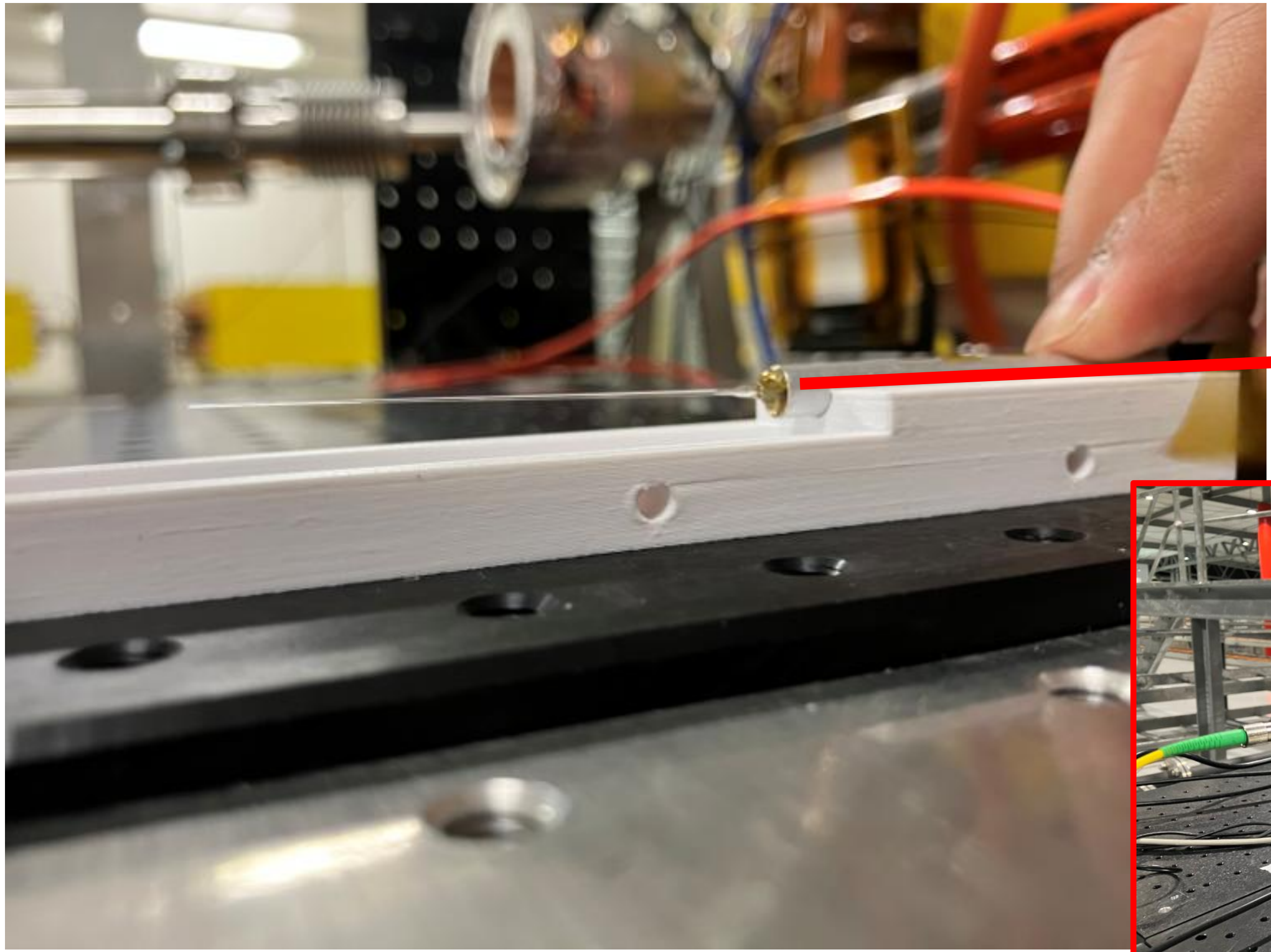
How do photonic lanterns work?



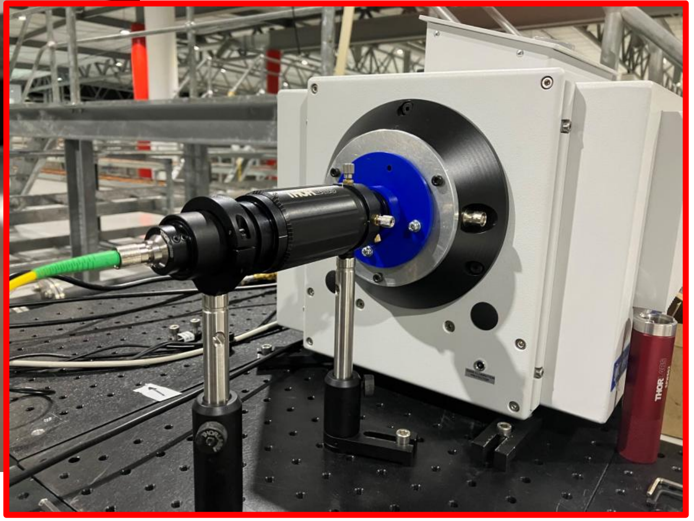


Fabricated by:

How do photonic lanterns work?



To streak cam

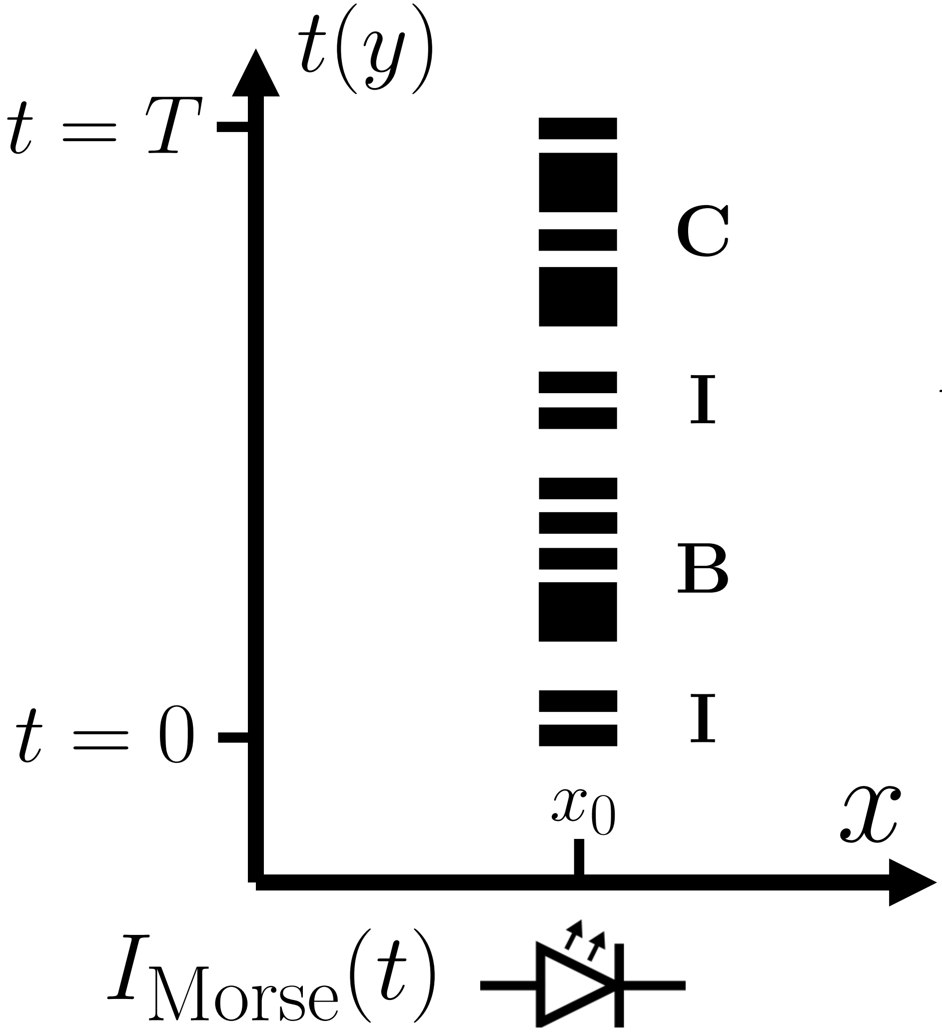


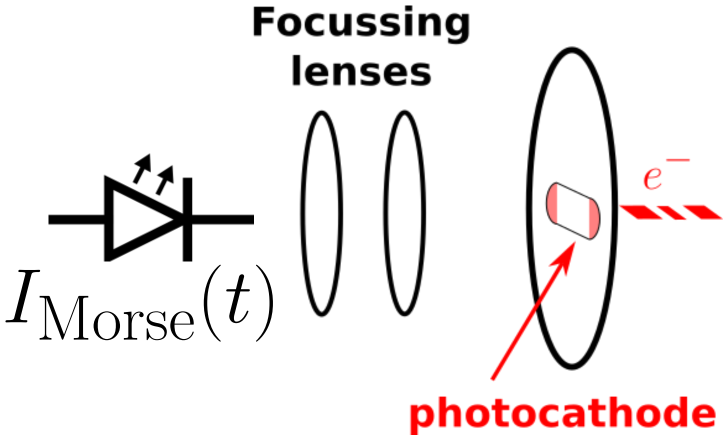
Fabricated by:

THE UNIVERSITY OF SYDNEY

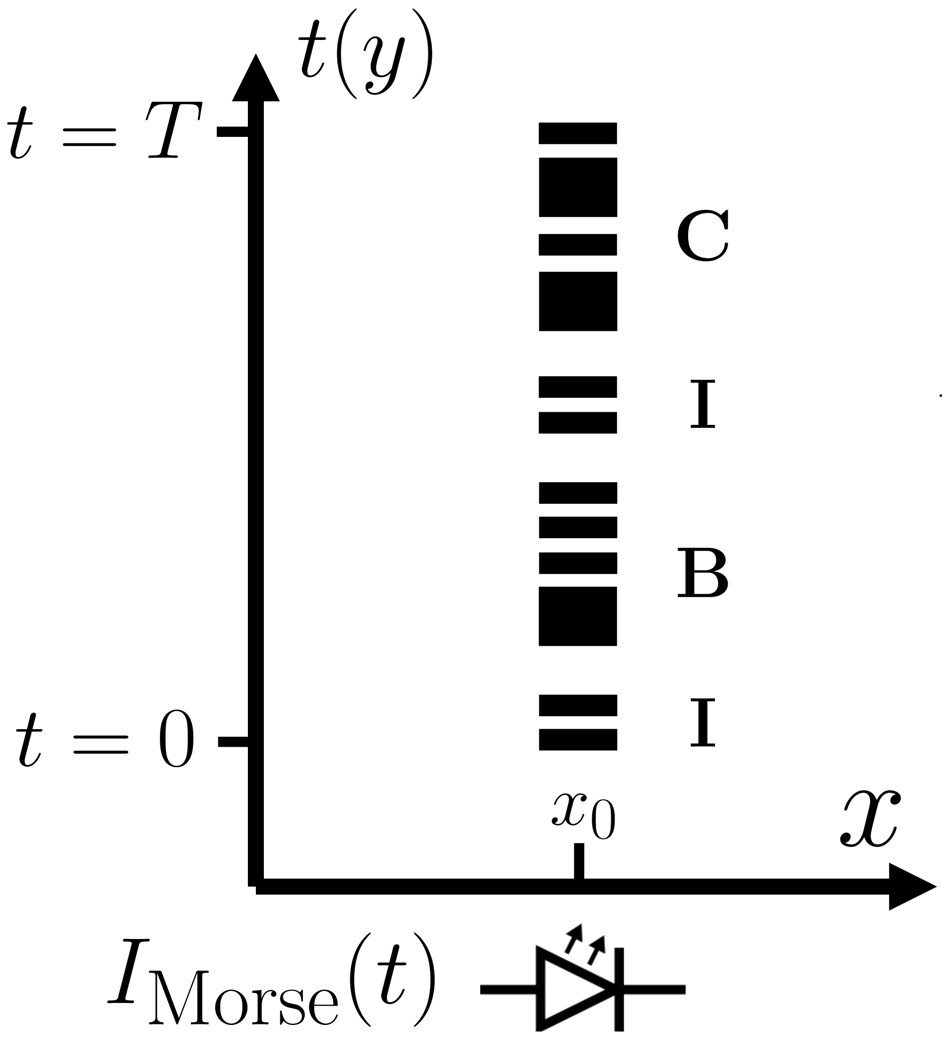
SAIL
SYDNEY ASTROPHOTONIC INSTRUMENTATION LABORATORY

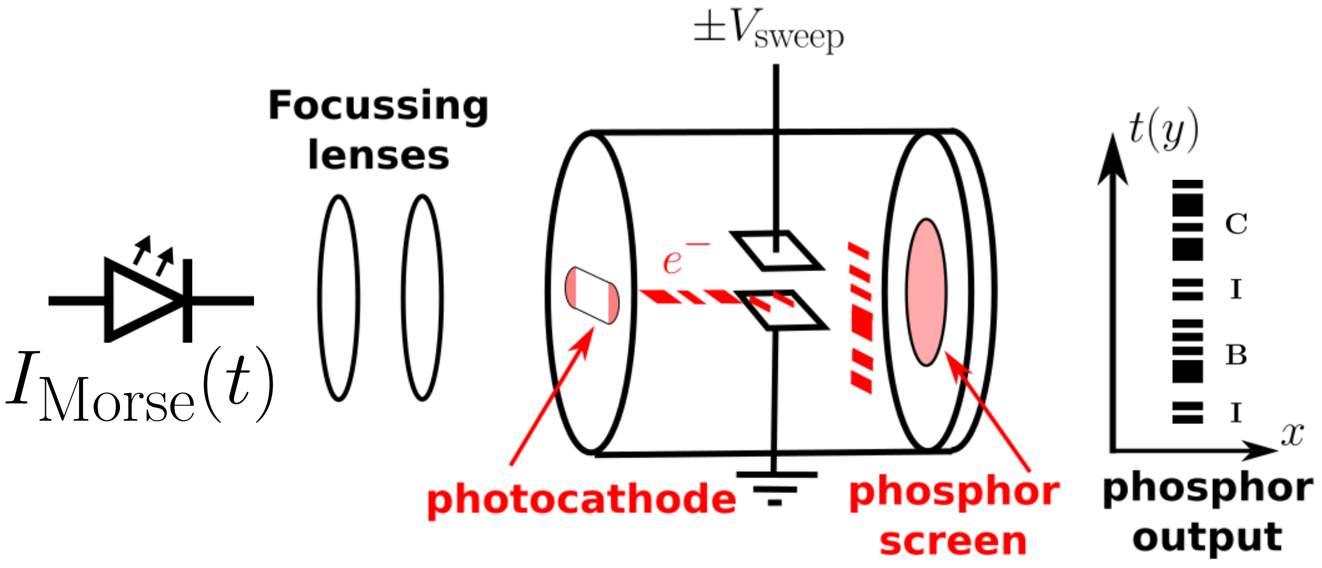
Streak cameras: a brief conceptual guide



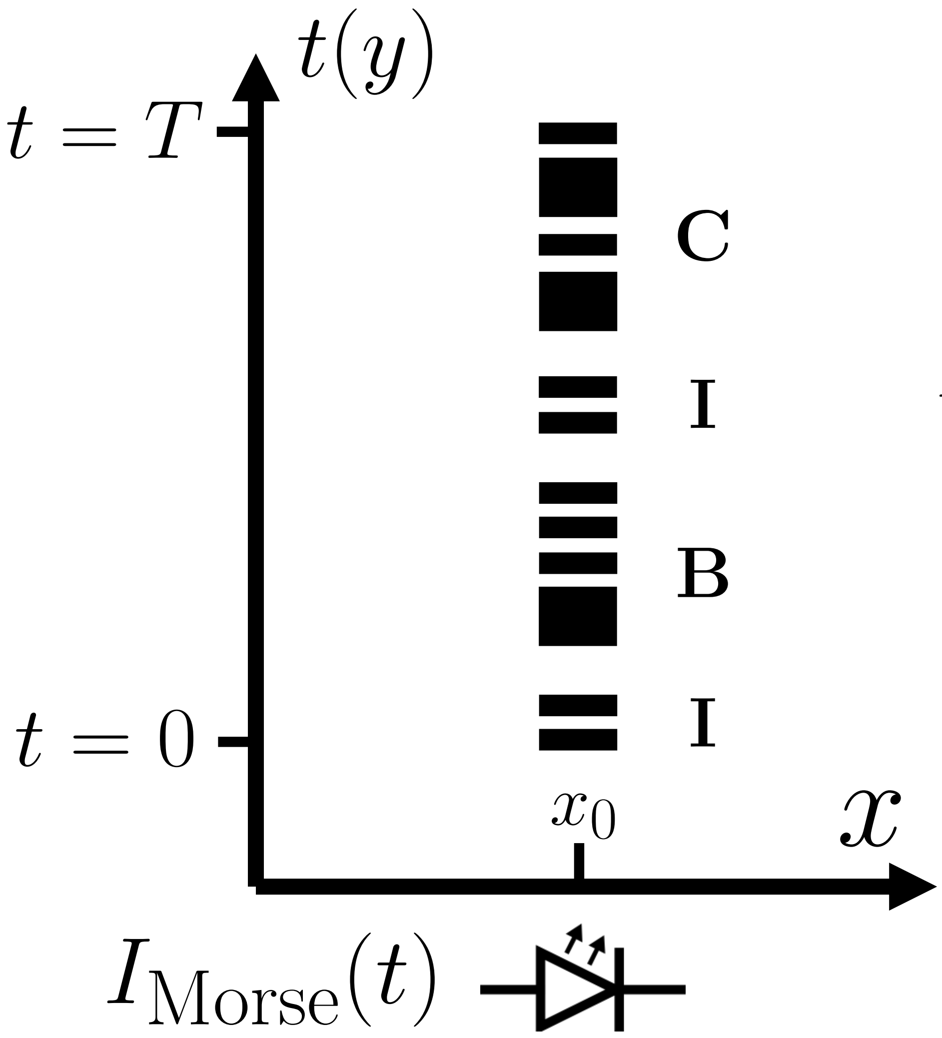


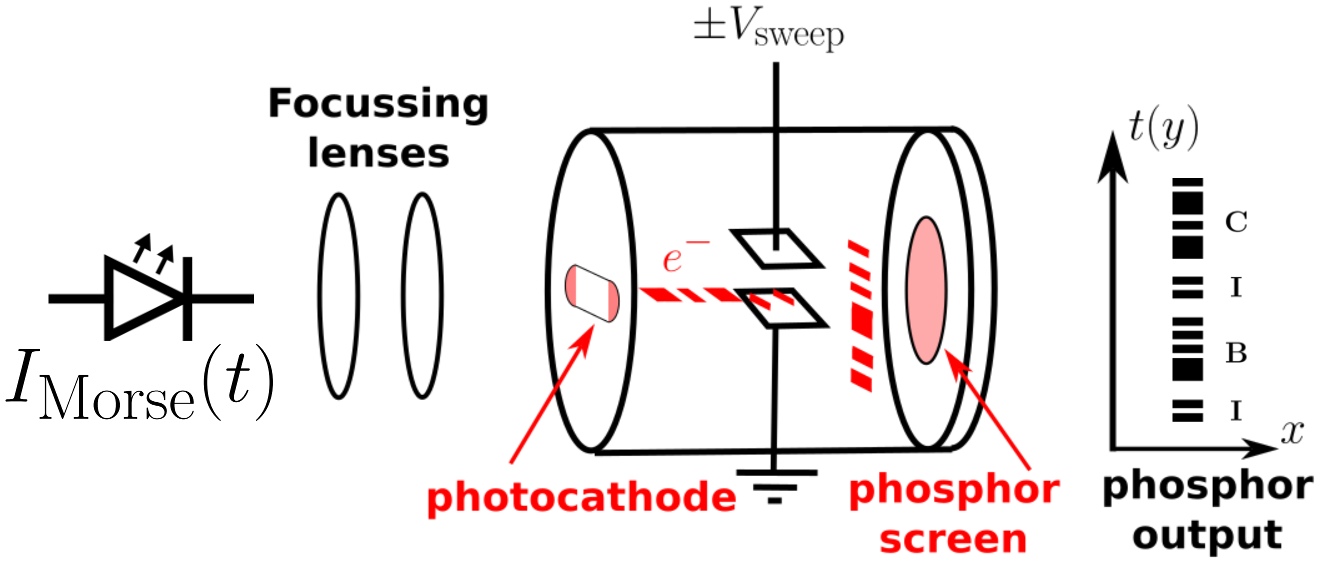
Streak cameras: a brief conceptual guide





Streak cameras: a brief conceptual guide

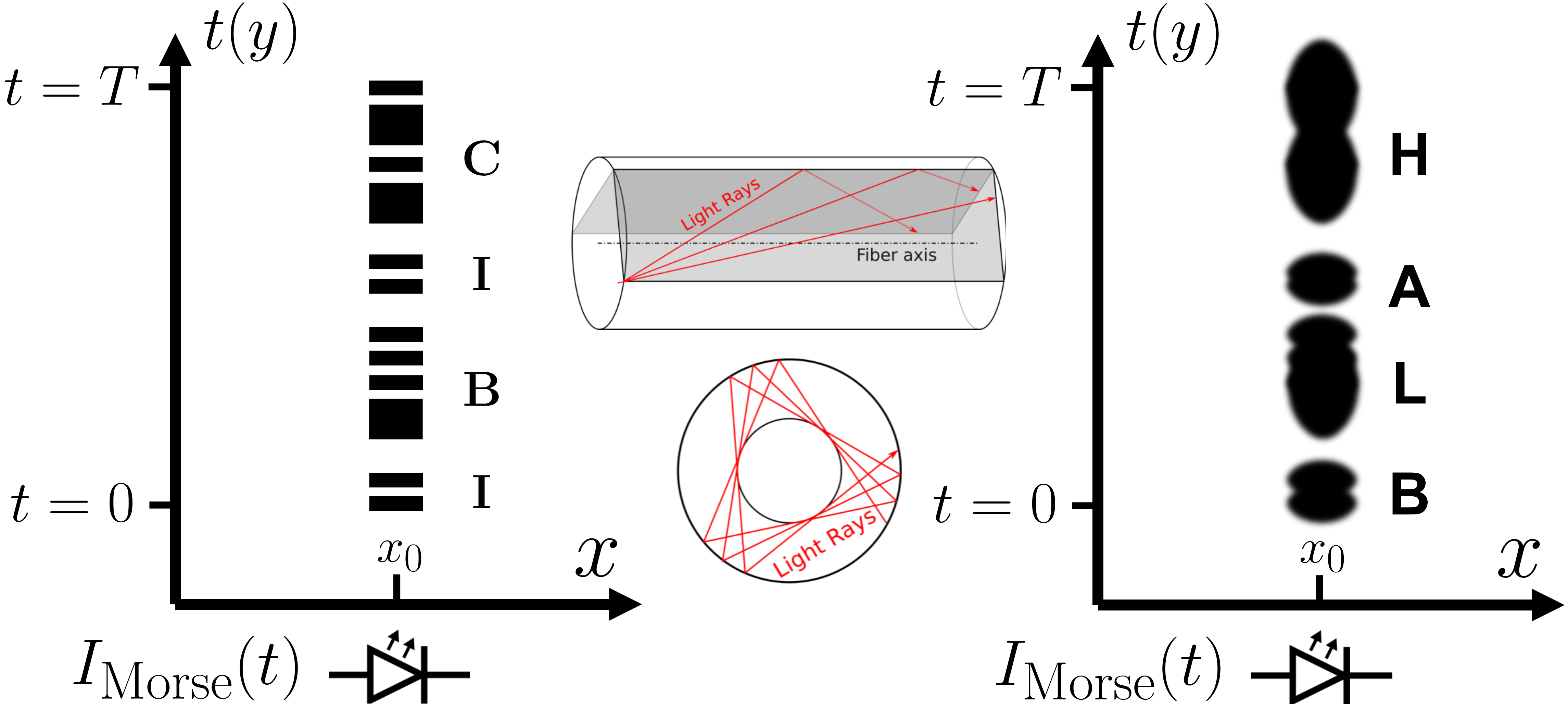




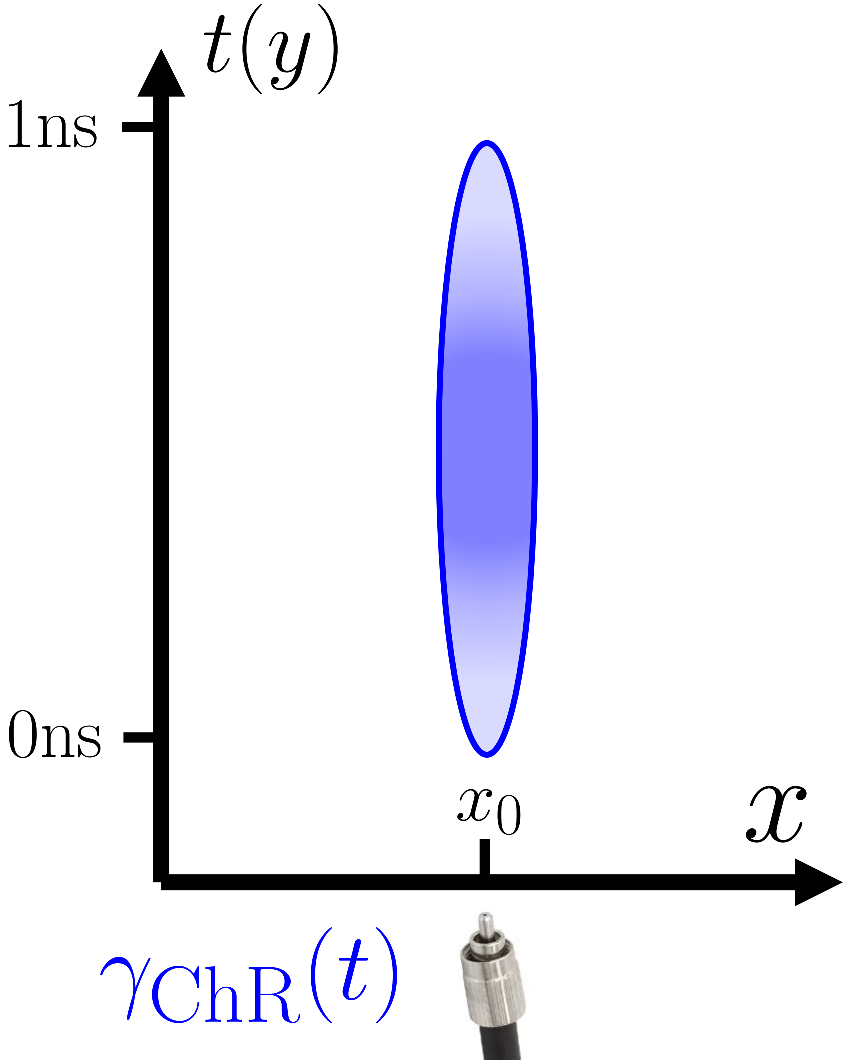
Morse transcription analogy

1. Paintbrush size ↔ Point-Spread-Function
2. Write speed ↔ sweep speed (500ps/mm)
3. Paper movement ↔ shot-to-shot jitter
4. Limited ink ↔ poor SNR

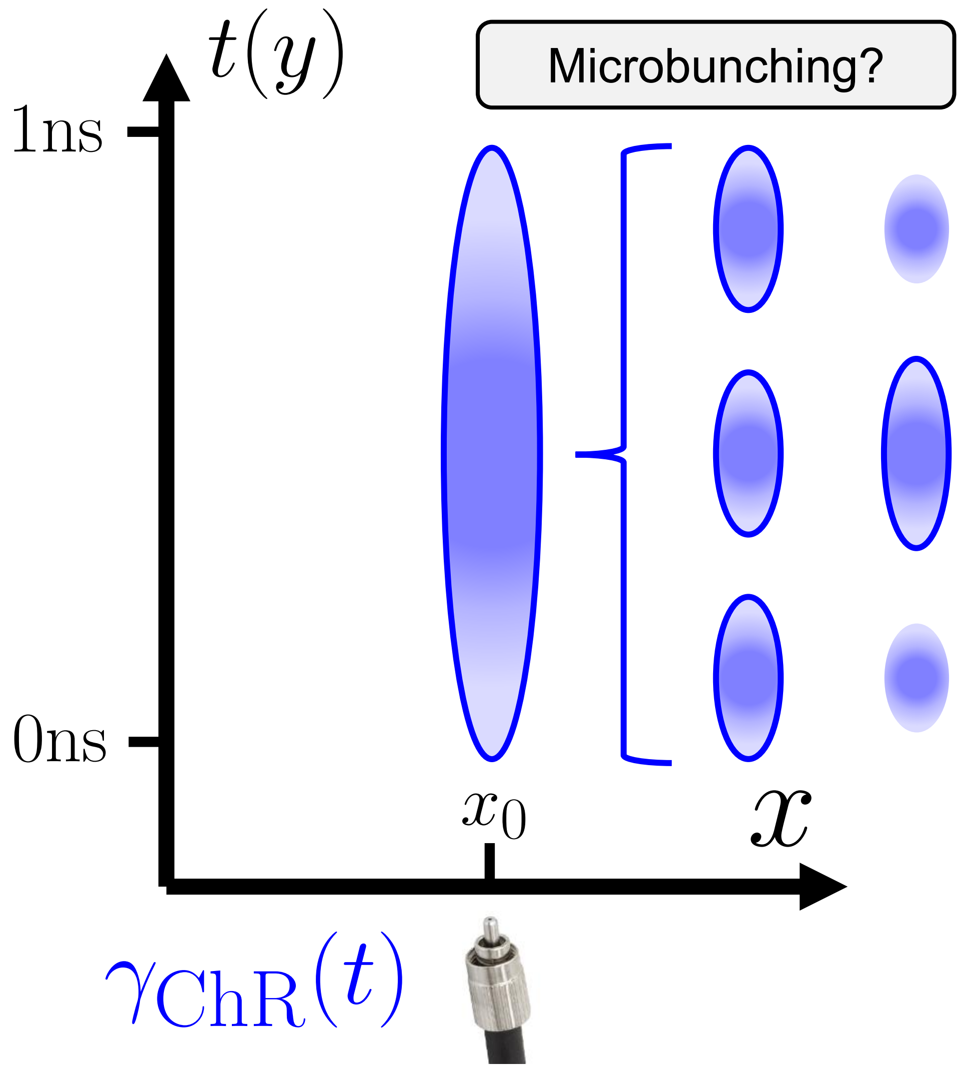
Dispersive broadening in action



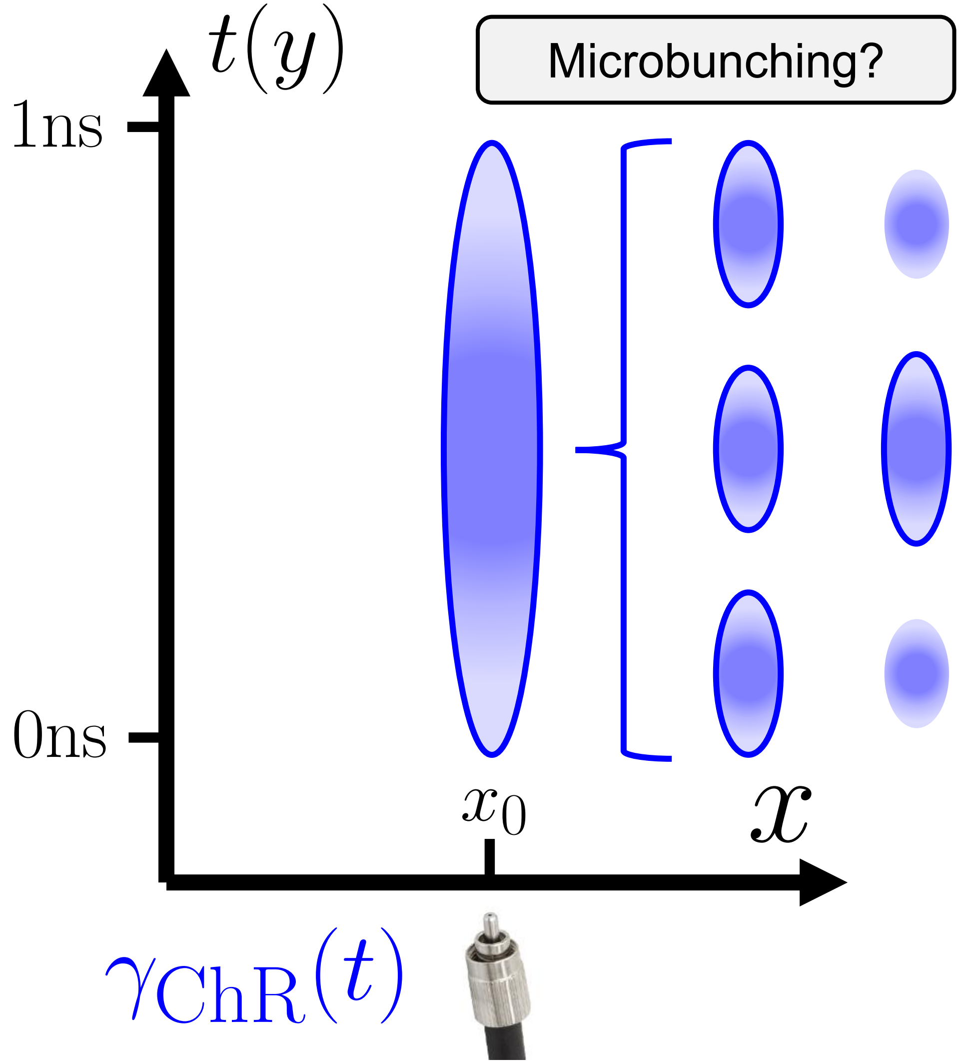
Back to reality: from Morse to Cherenkov

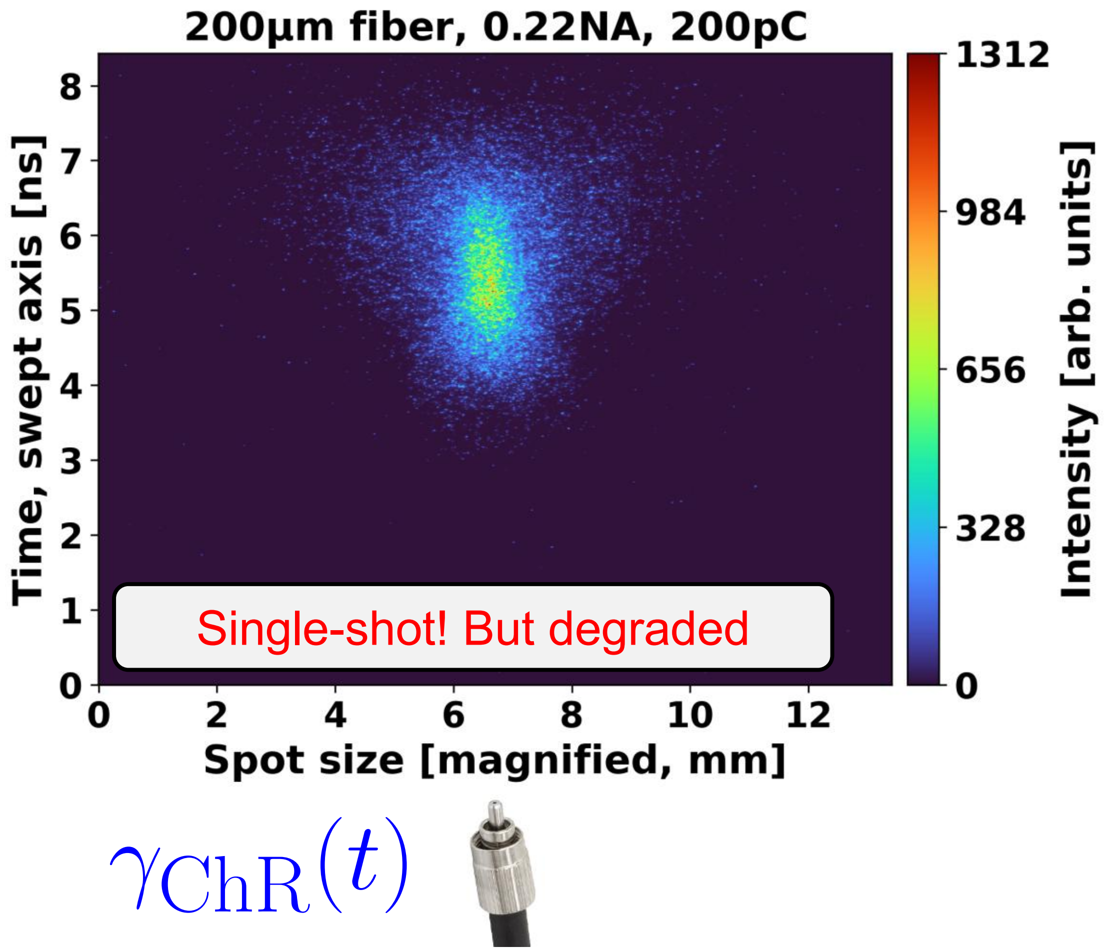


Back to reality: from Morse to Cherenkov

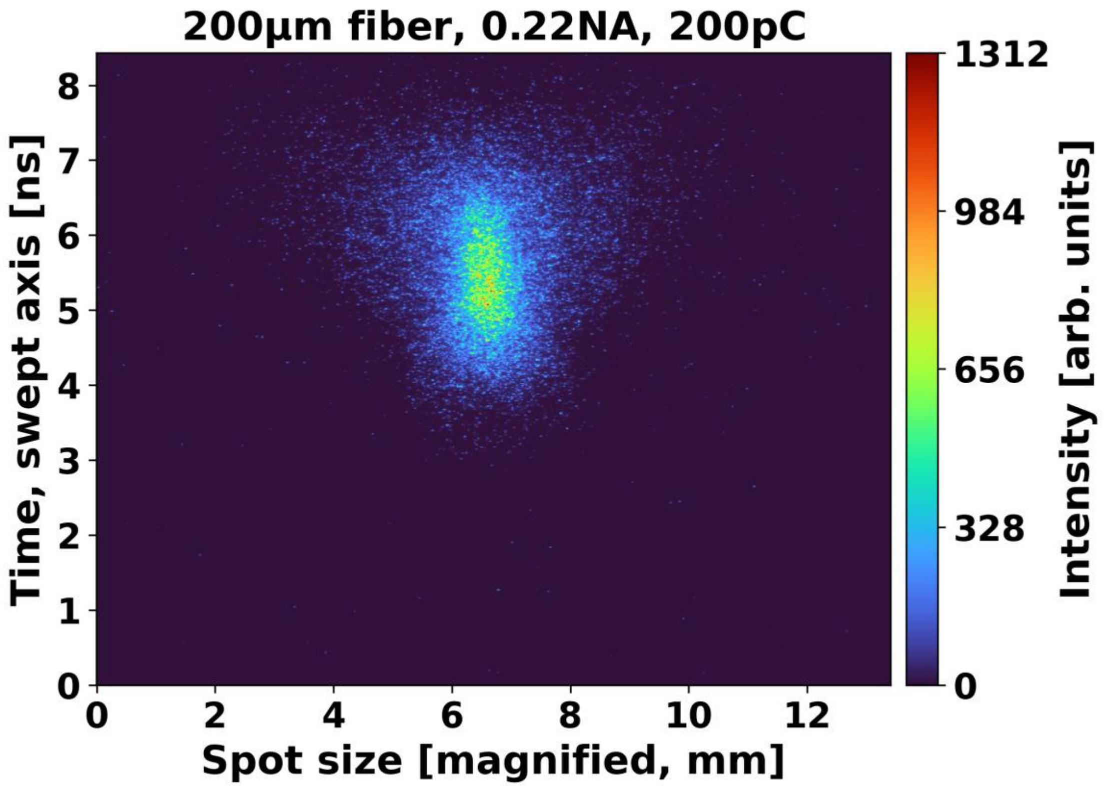


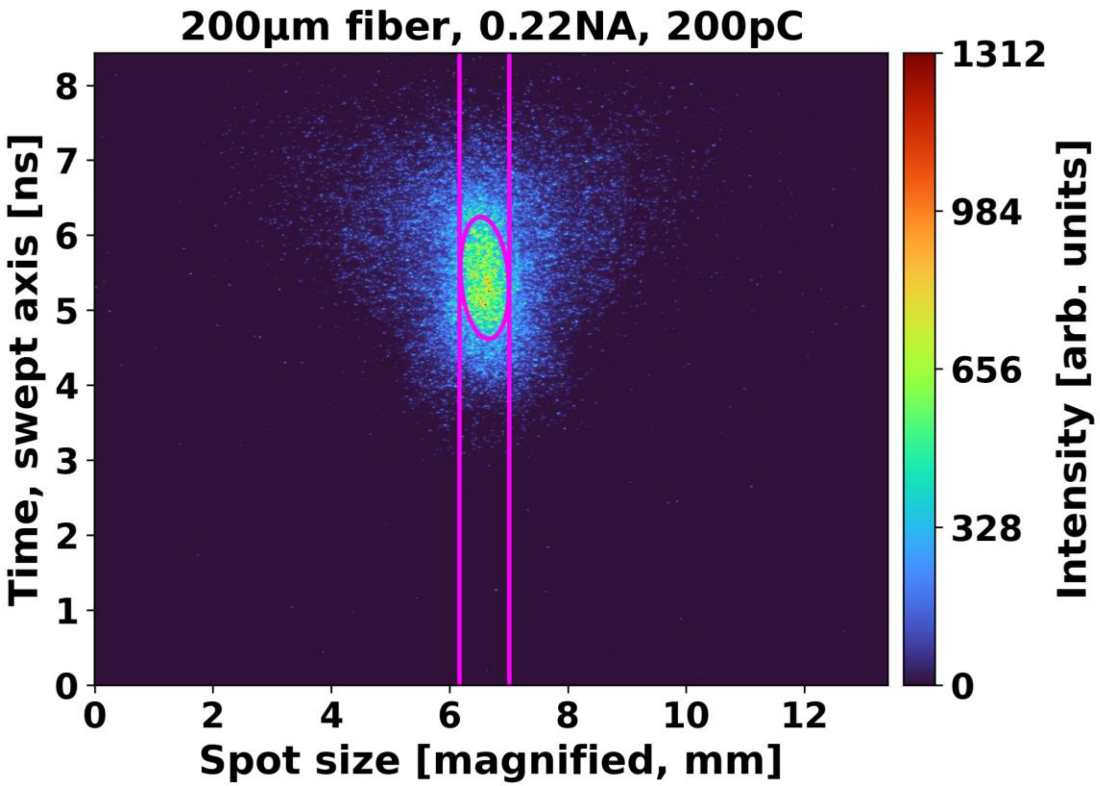
Back to reality: from Morse to Cherenkov



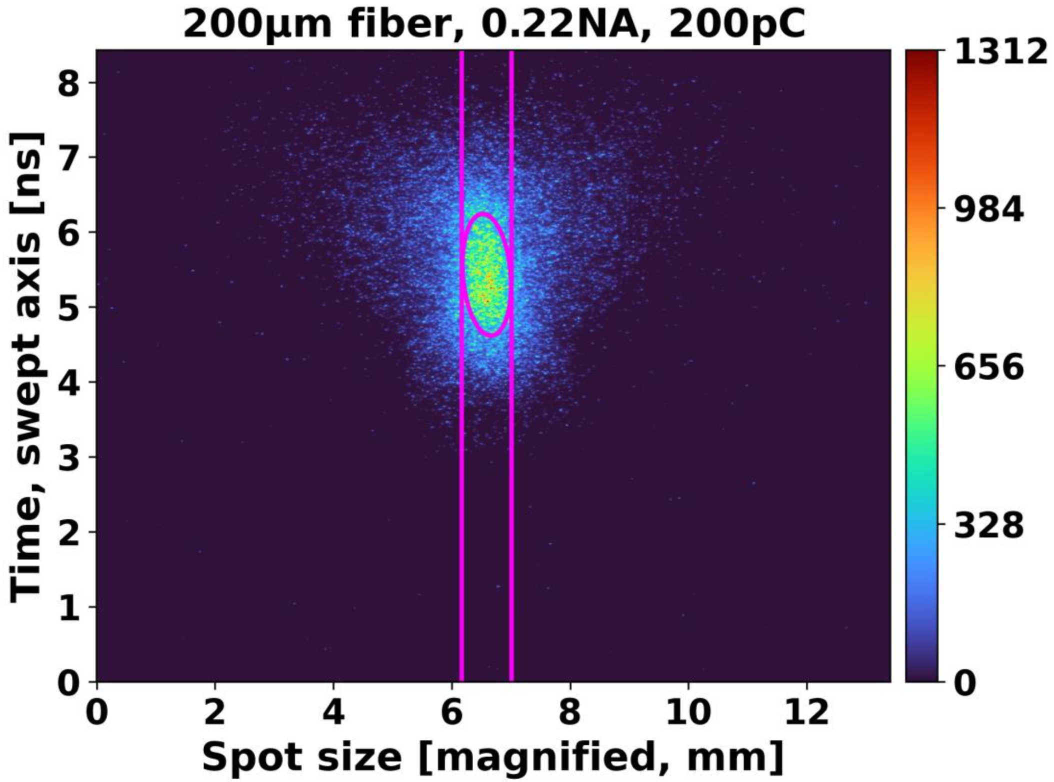


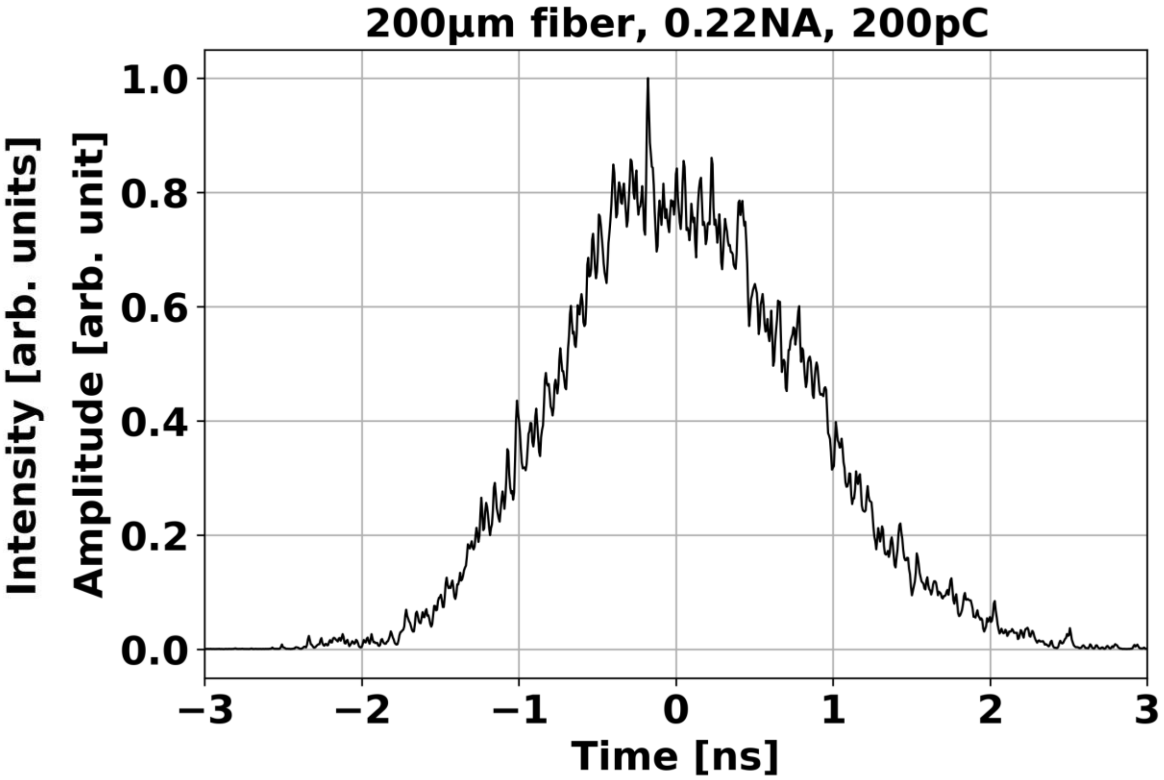
Excluding higher order skew modes



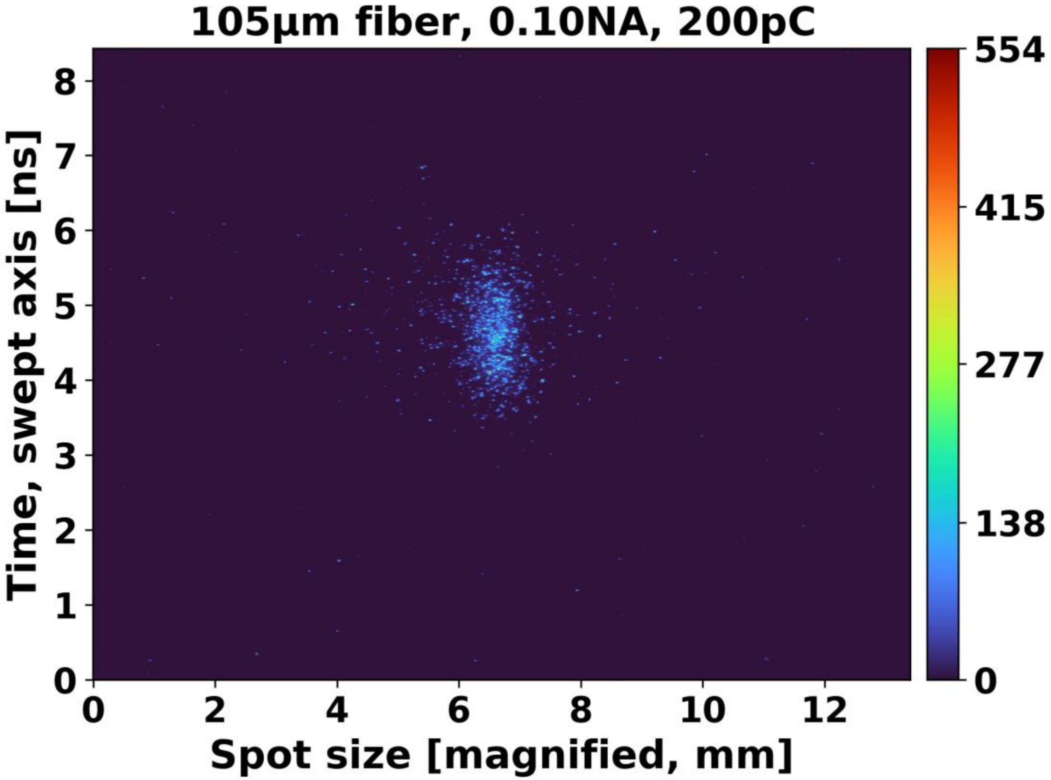


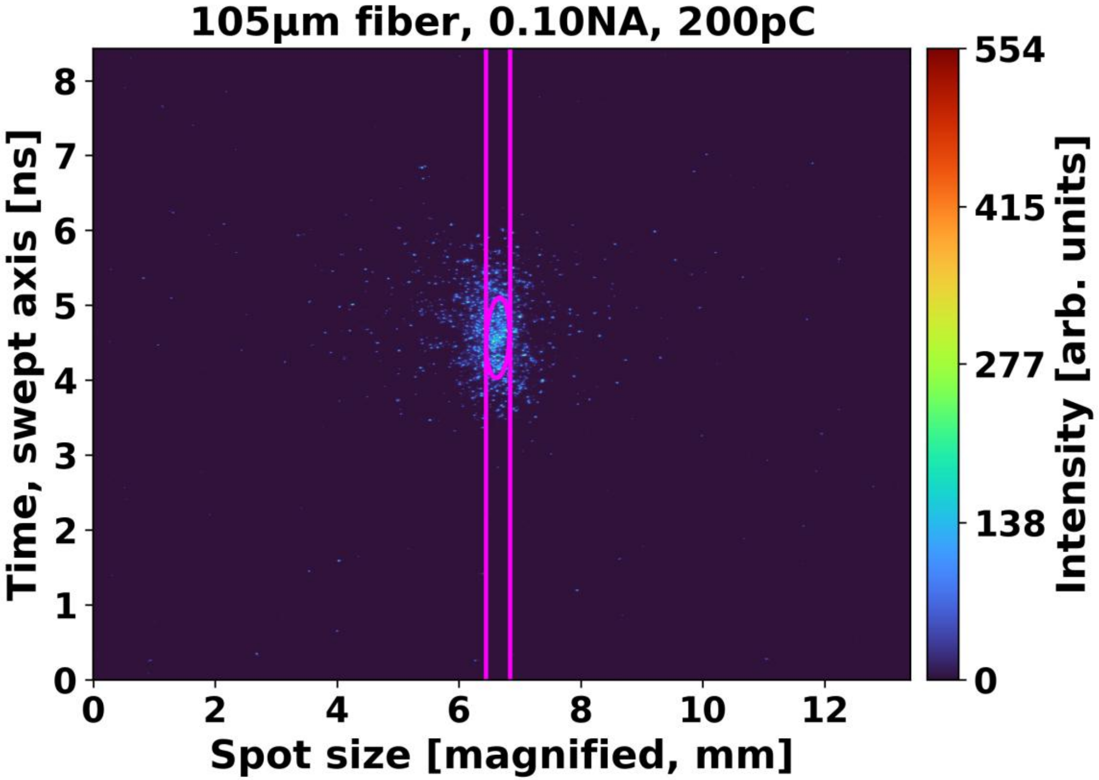
Excluding higher order skew modes



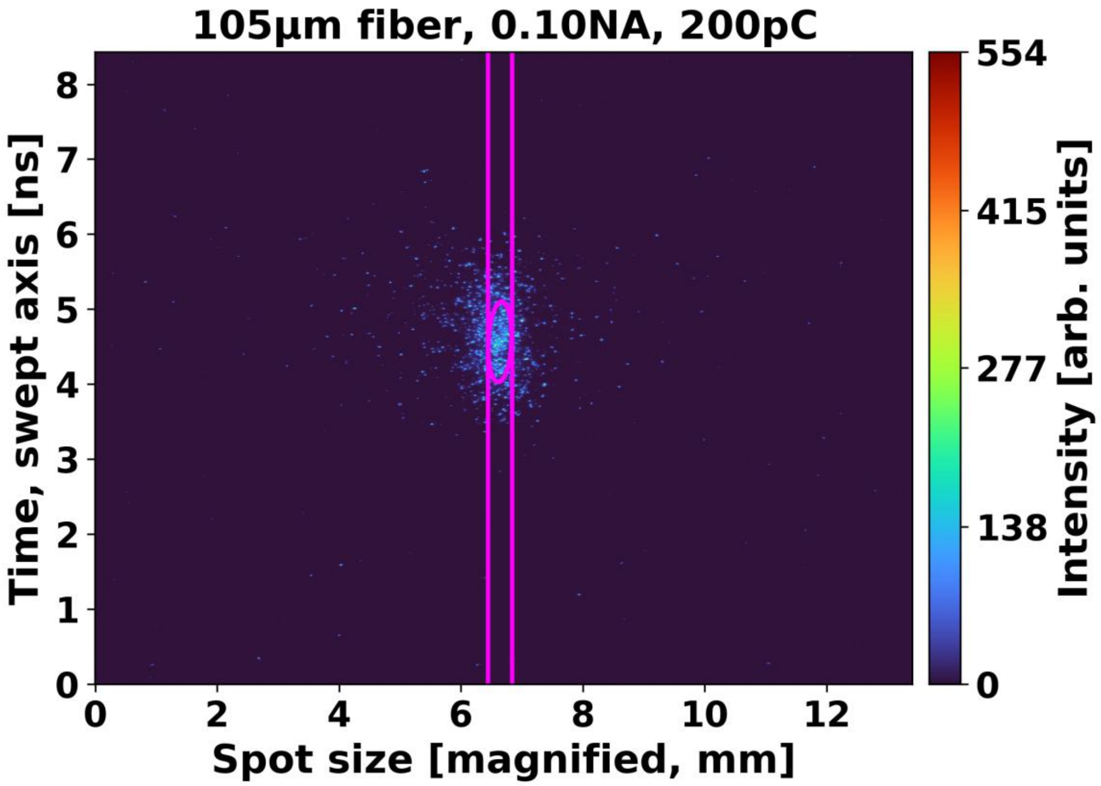


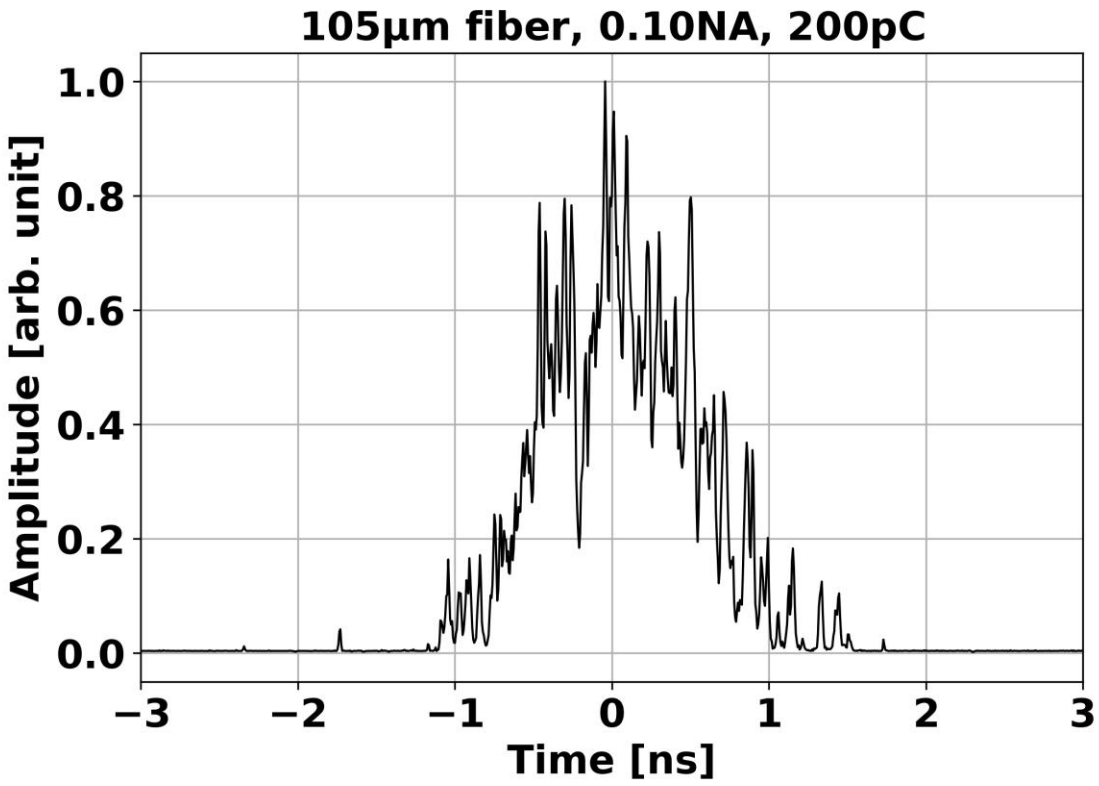
Reducing numerical aperture to 0.10NA



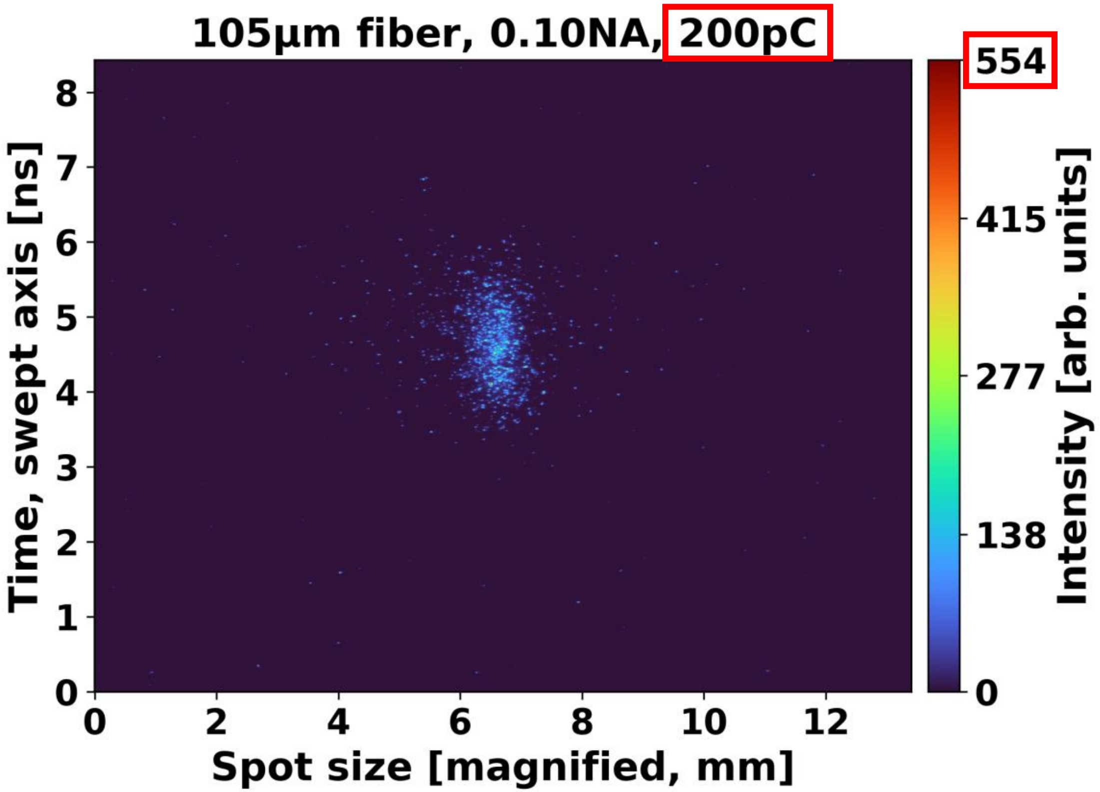


Reducing numerical aperture to 0.10NA

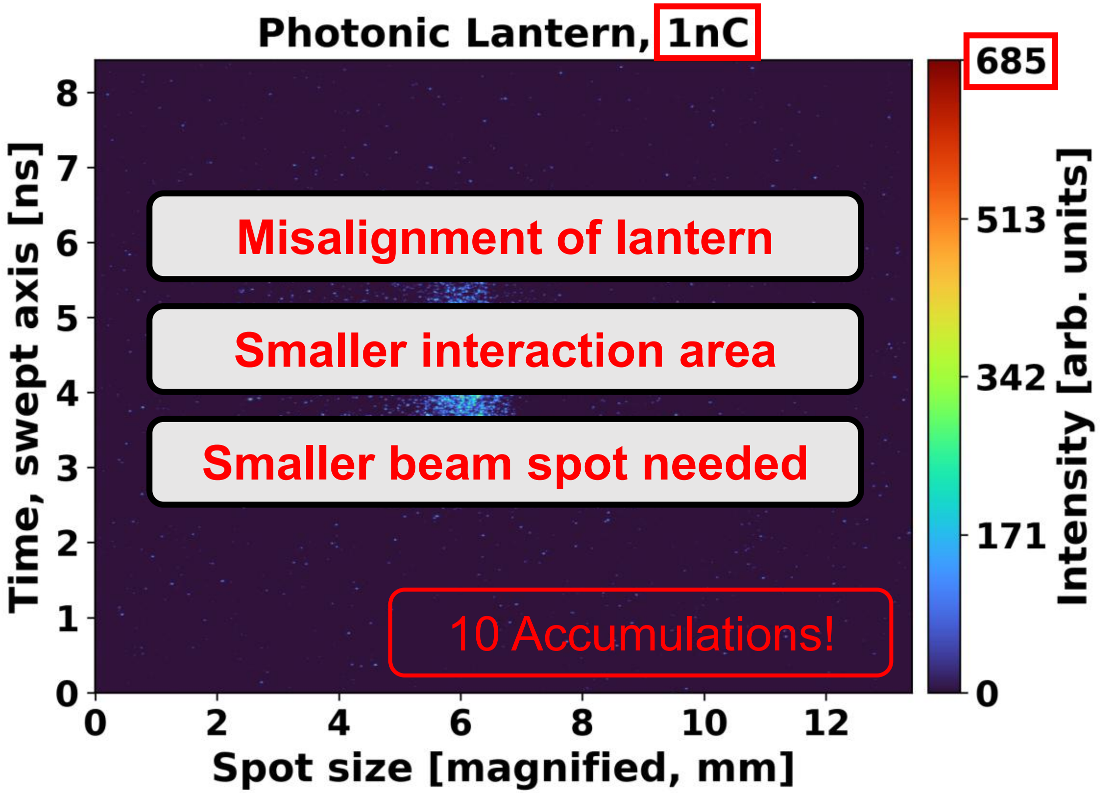




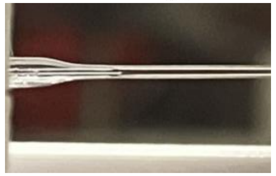
What about the Photonic lantern?



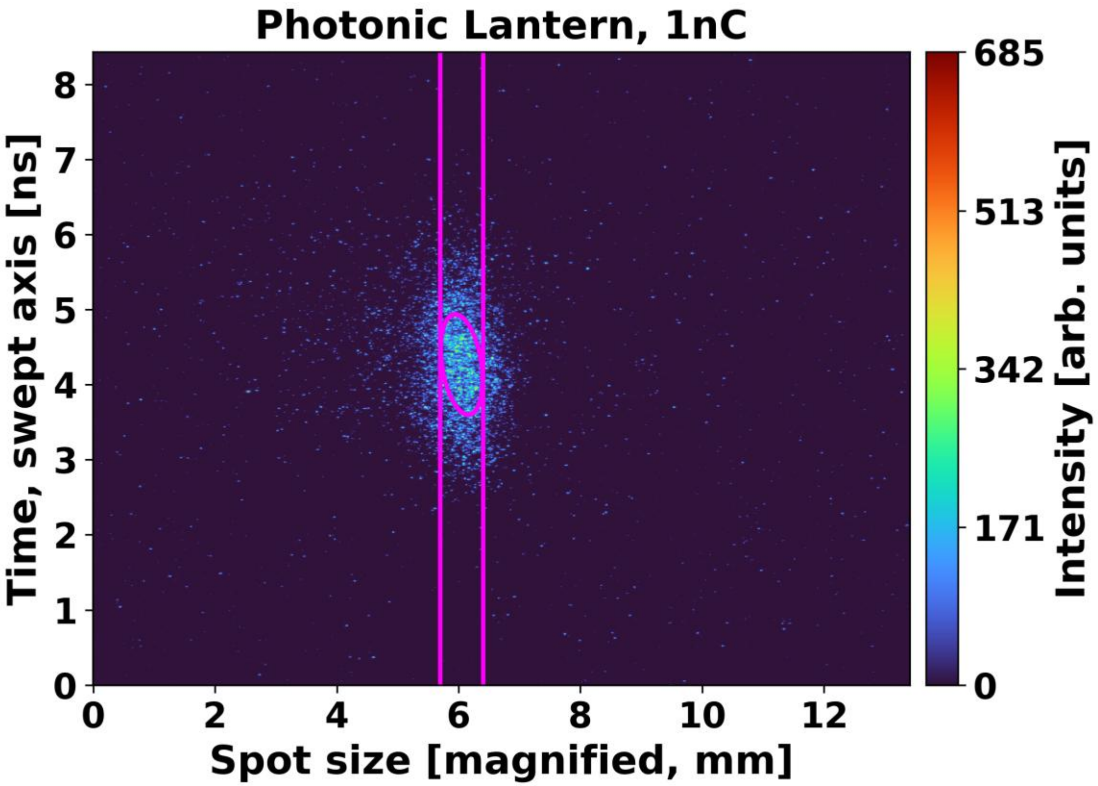
$\gamma_{\mathrm{ChR}}(t)$

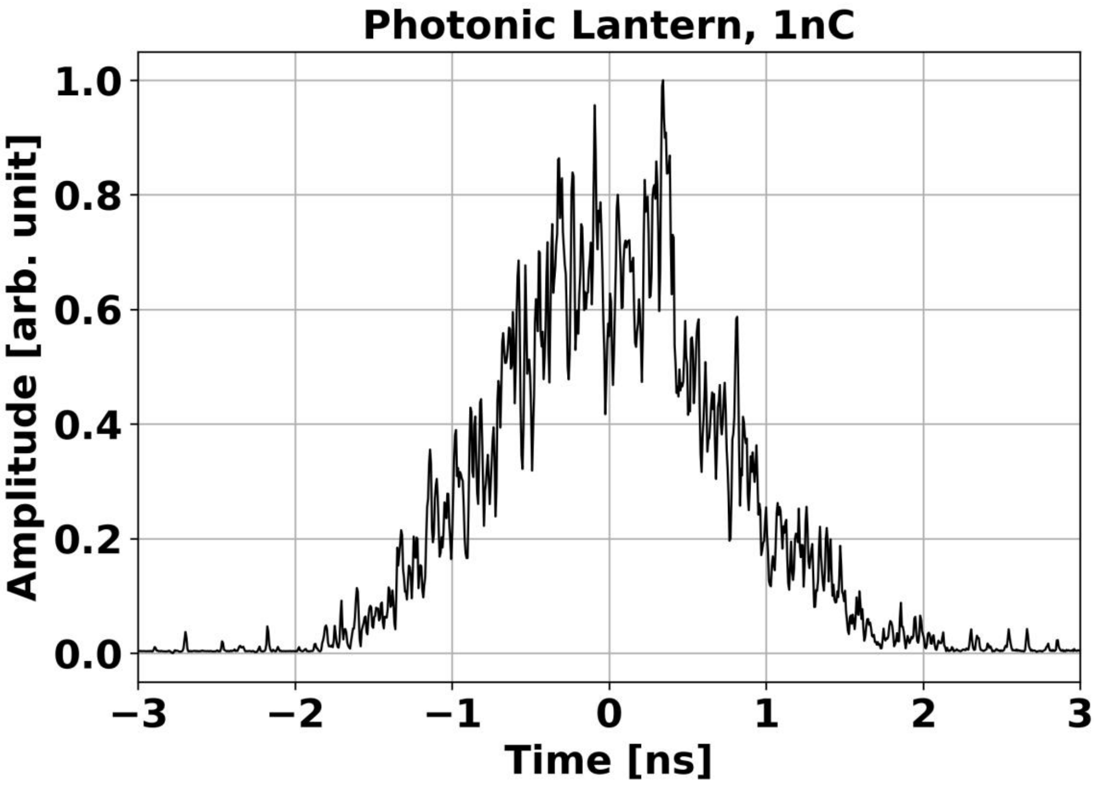


$\gamma_{\mathrm{ChR}}(t)$

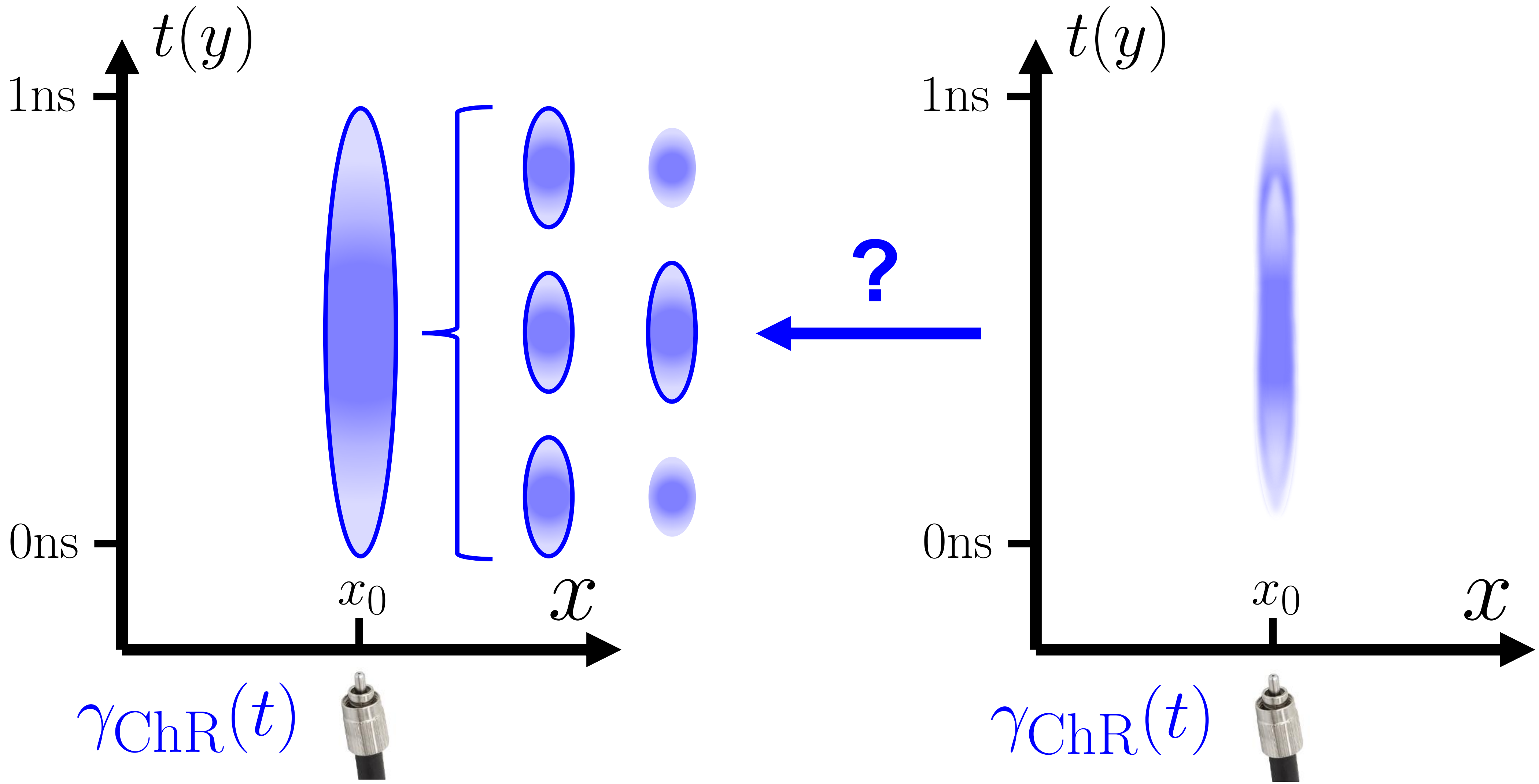


What about the Photonic lantern?

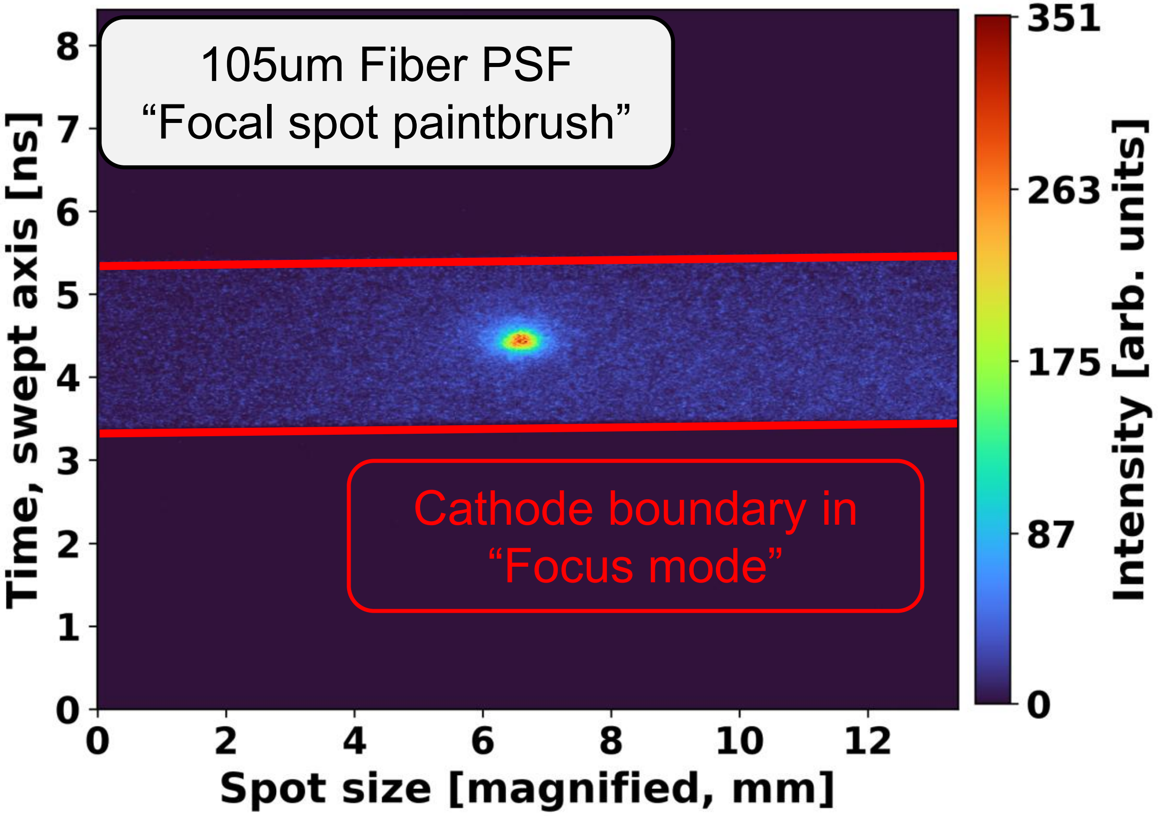


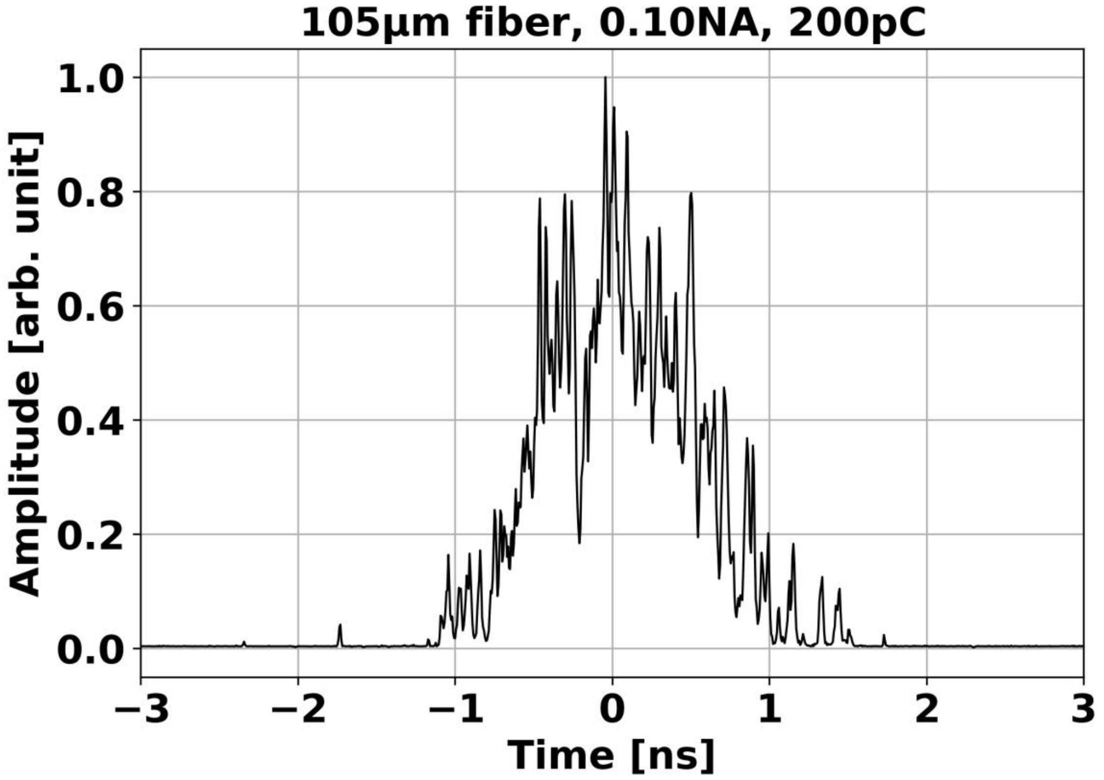


Any hope for *some* signal recovery?

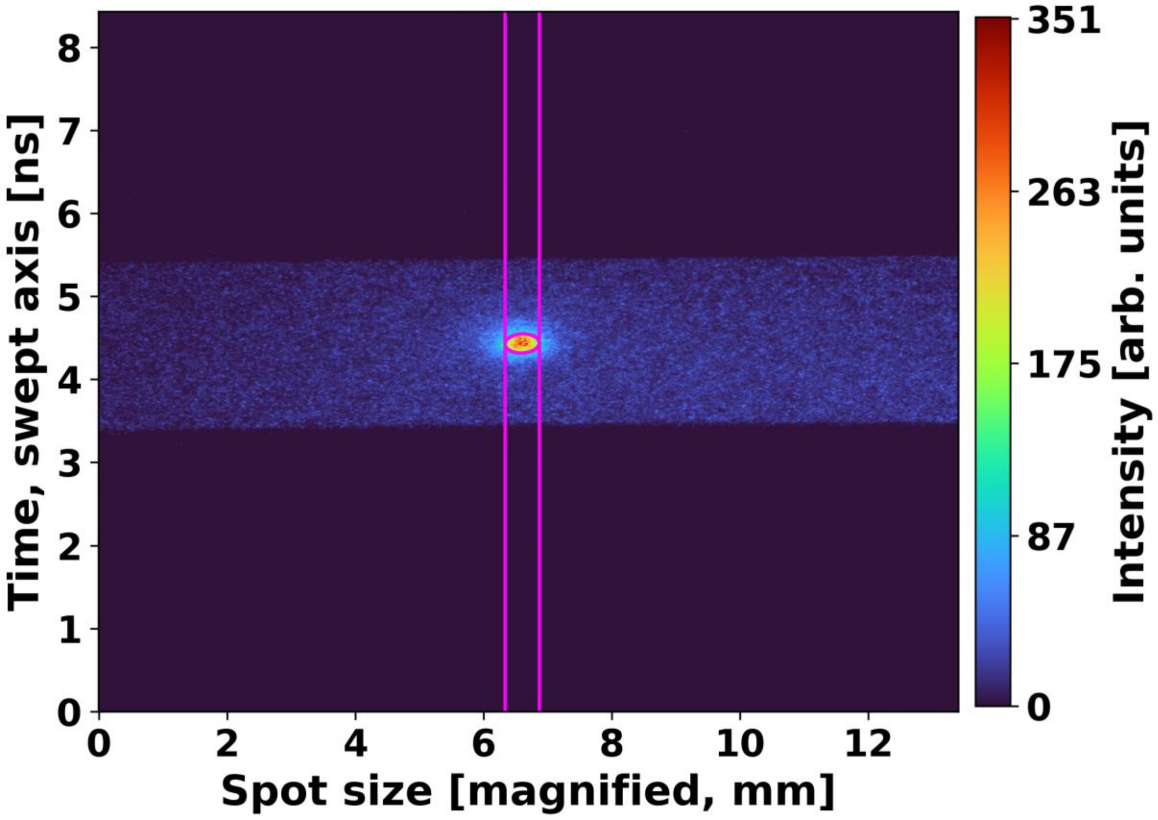


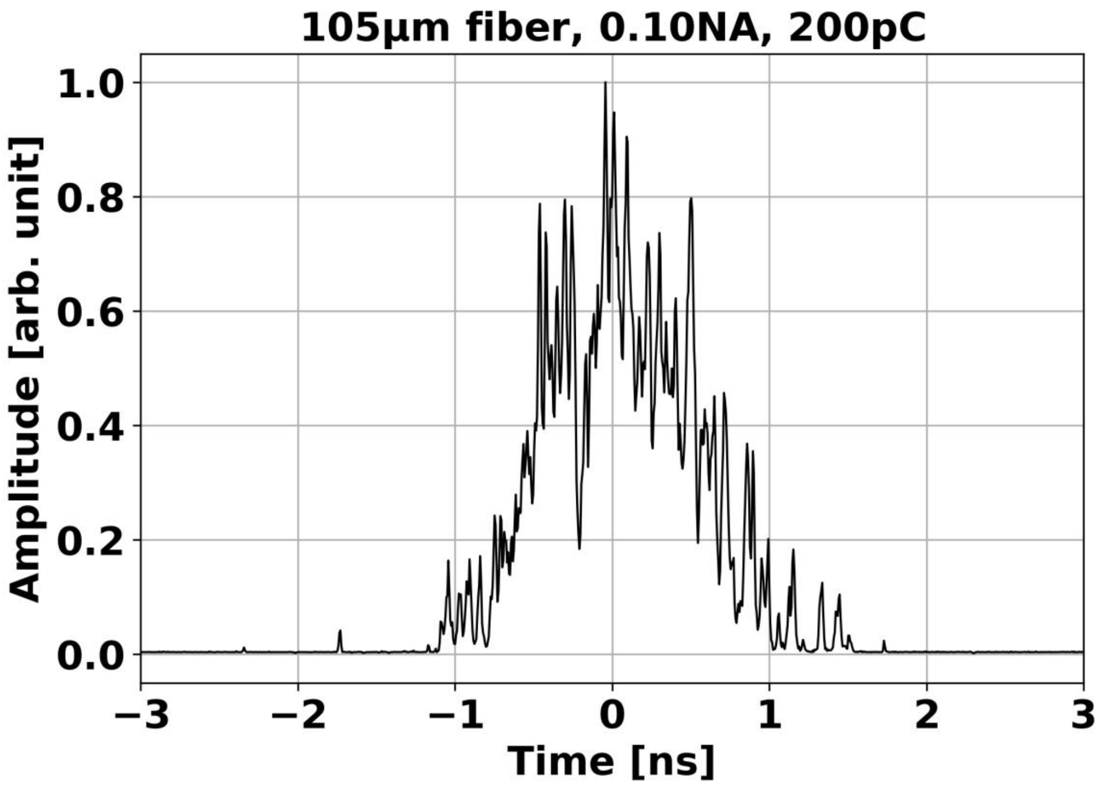
So, what is our paintbrush size? (It's not small…)





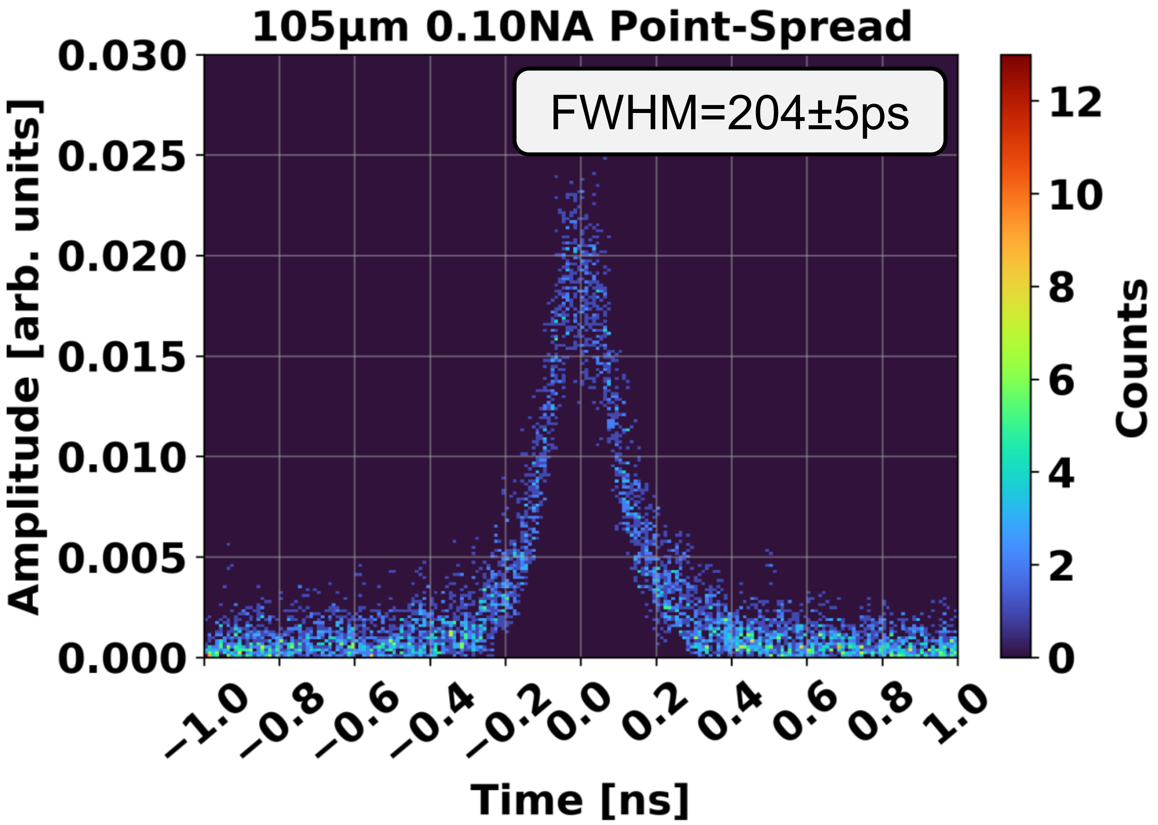
So, what is our paintbrush size? (It’s not small…)

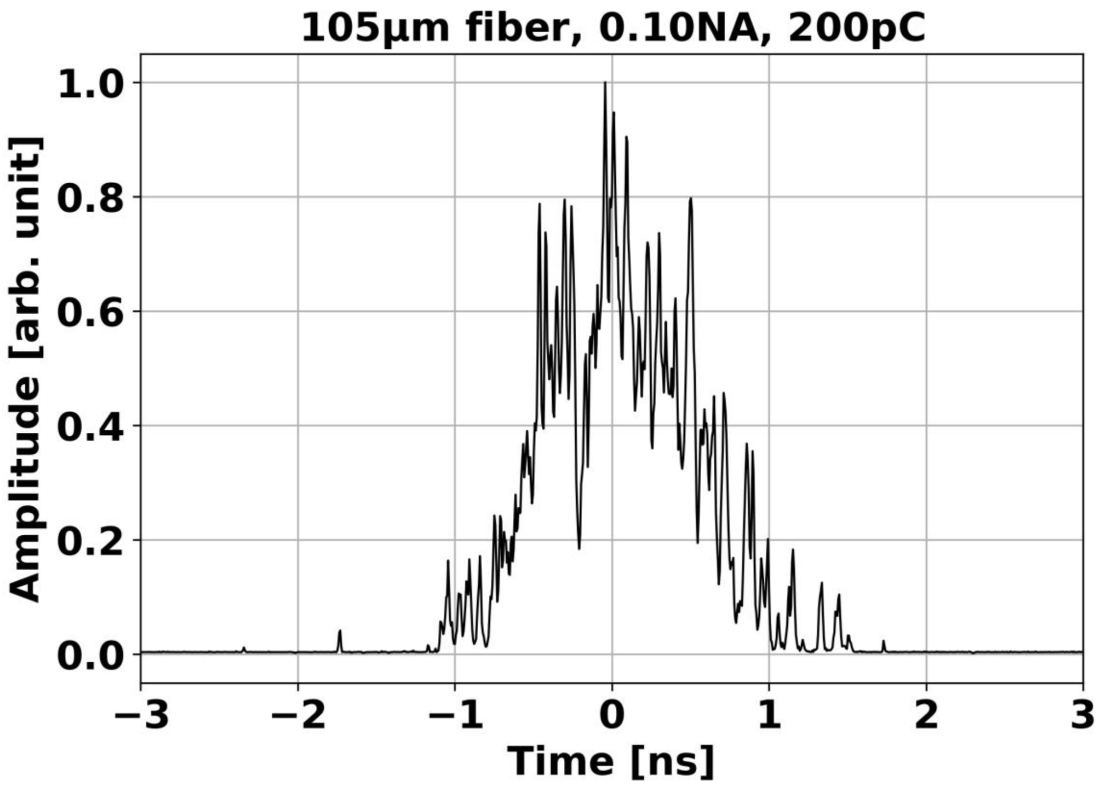




So, what is our paintbrush size? (It's not small…)

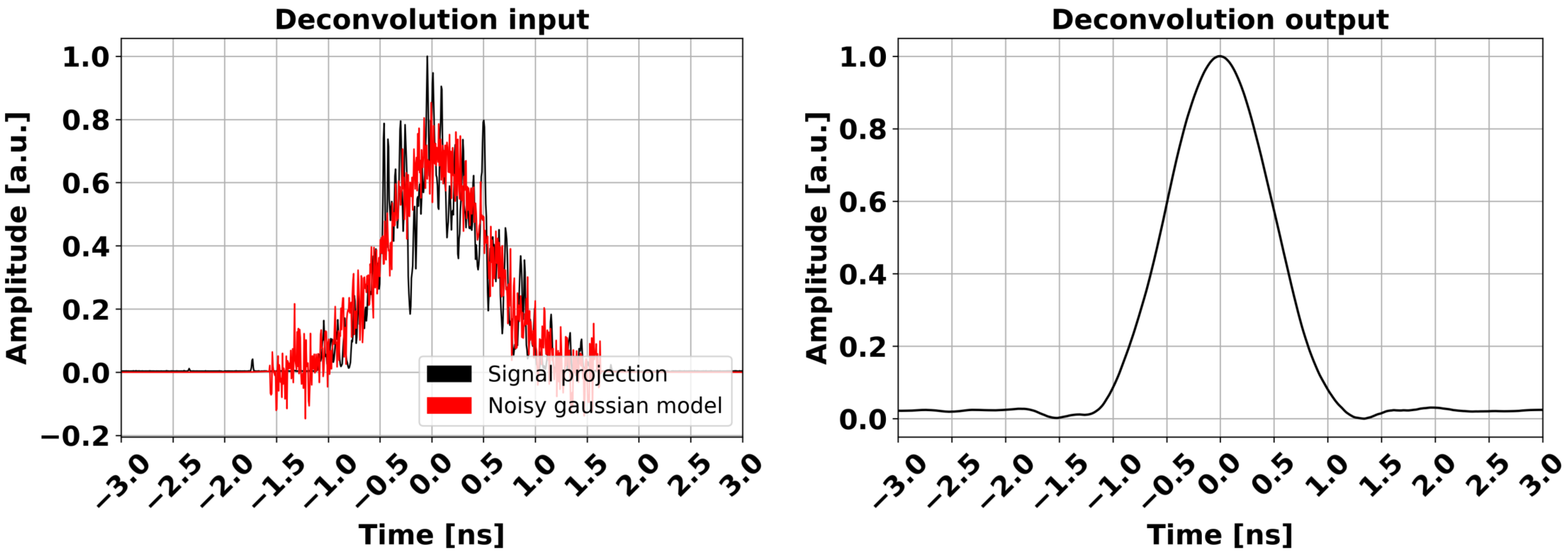
For the lantern, FWHM: 341±7ps!





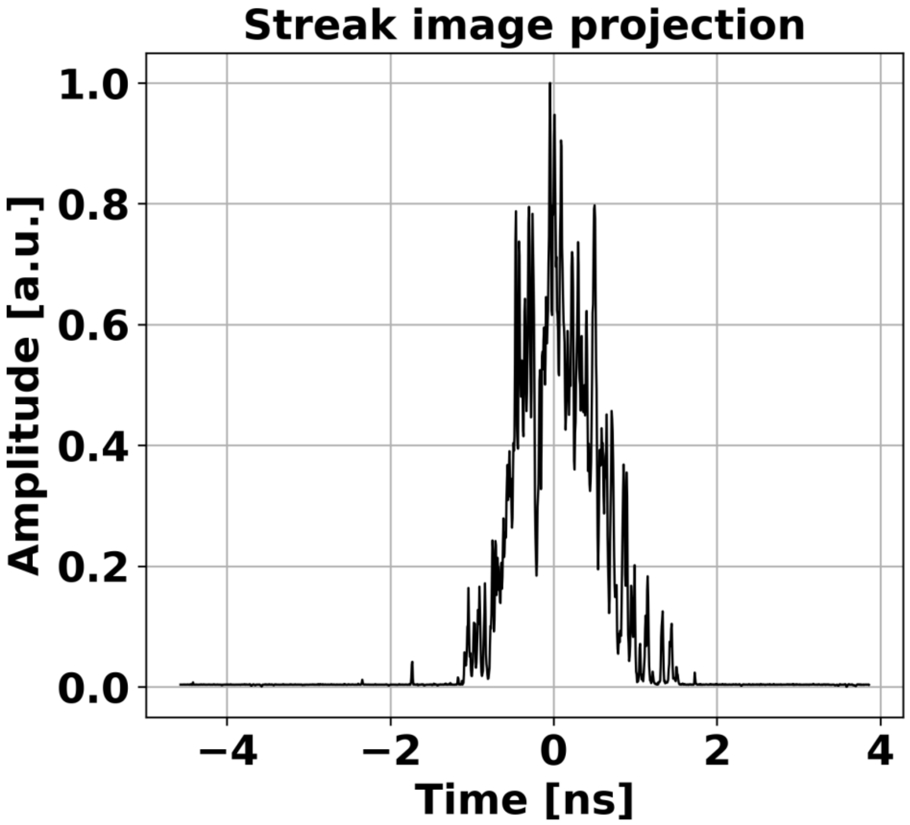
Deconvolution: a sanity check

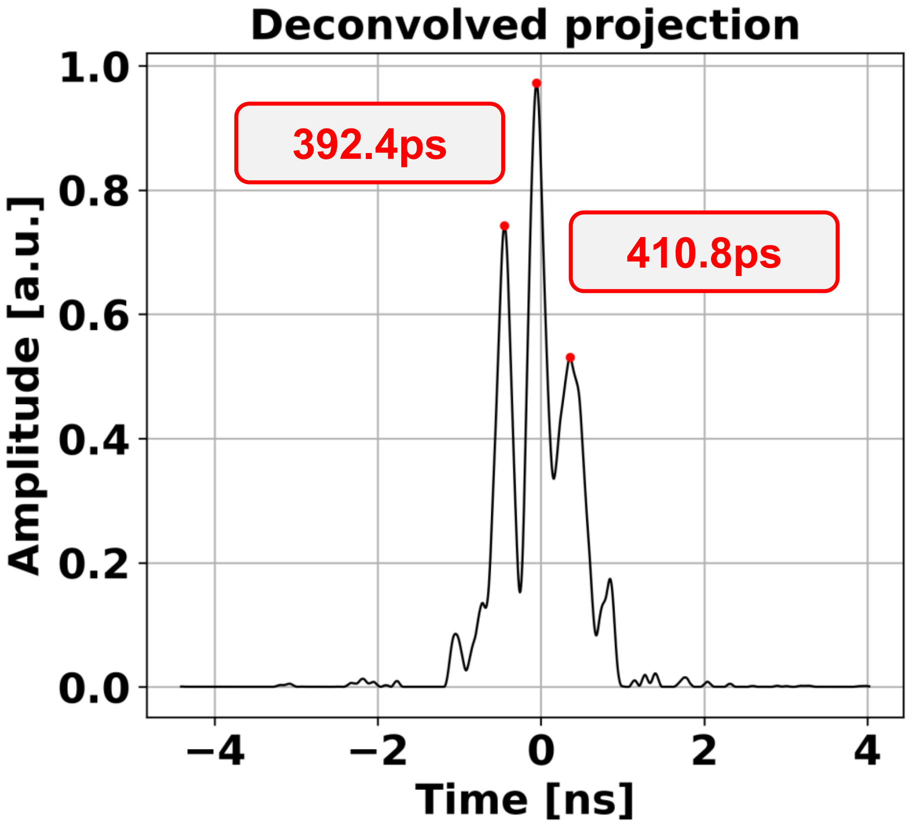
$$g_{\text{obs}}(t) = h_{\text{spot}}(t) * f_{\text{signal}}(t)$$



Deconvolution: 200pC, 105um 0.10NA fiber

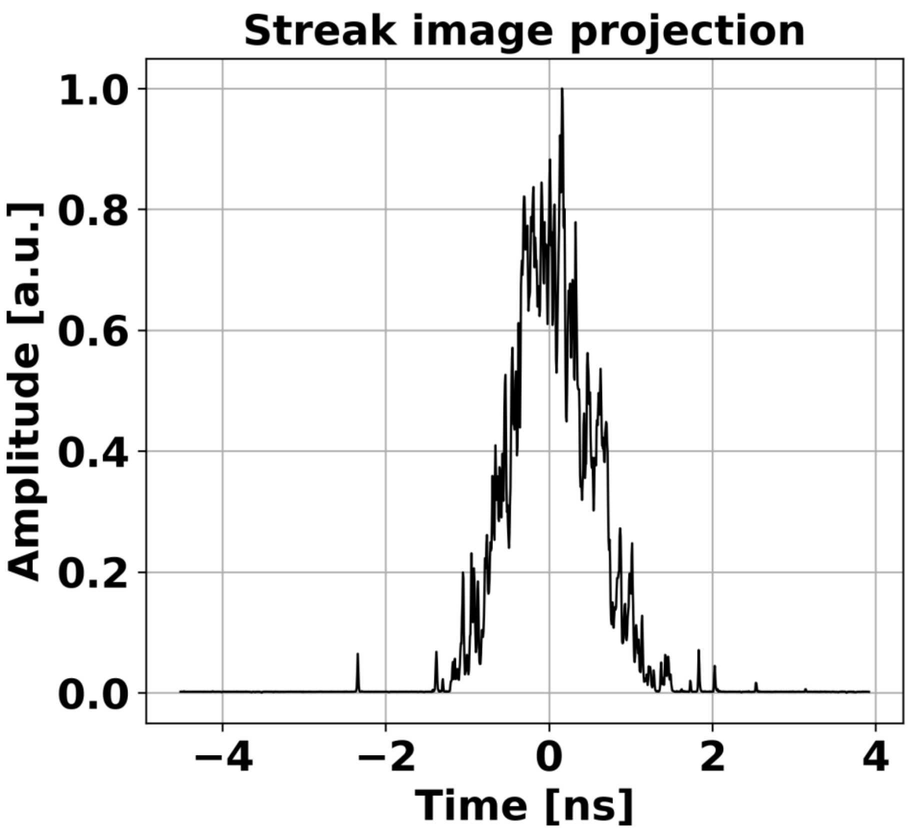
$$g_{\mathrm{obs}}(t) = h_{\mathrm{spot}}(t) * f_{\mathrm{signal}}(t)$$

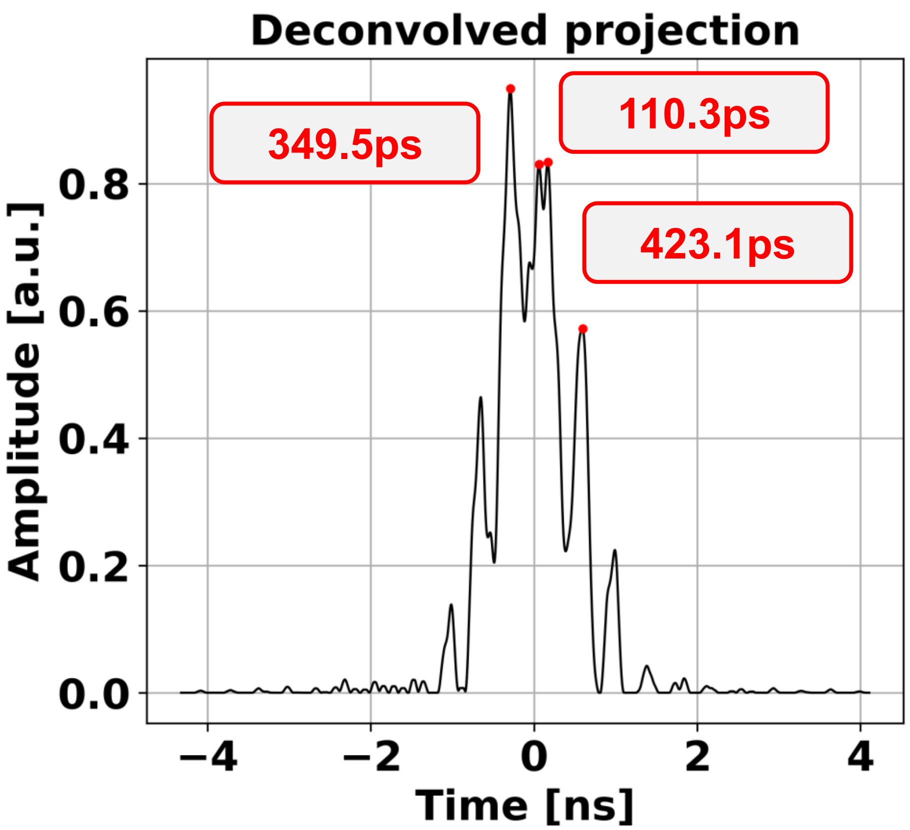




Deconvolution: 850pC, 105um, 0.10NA fiber

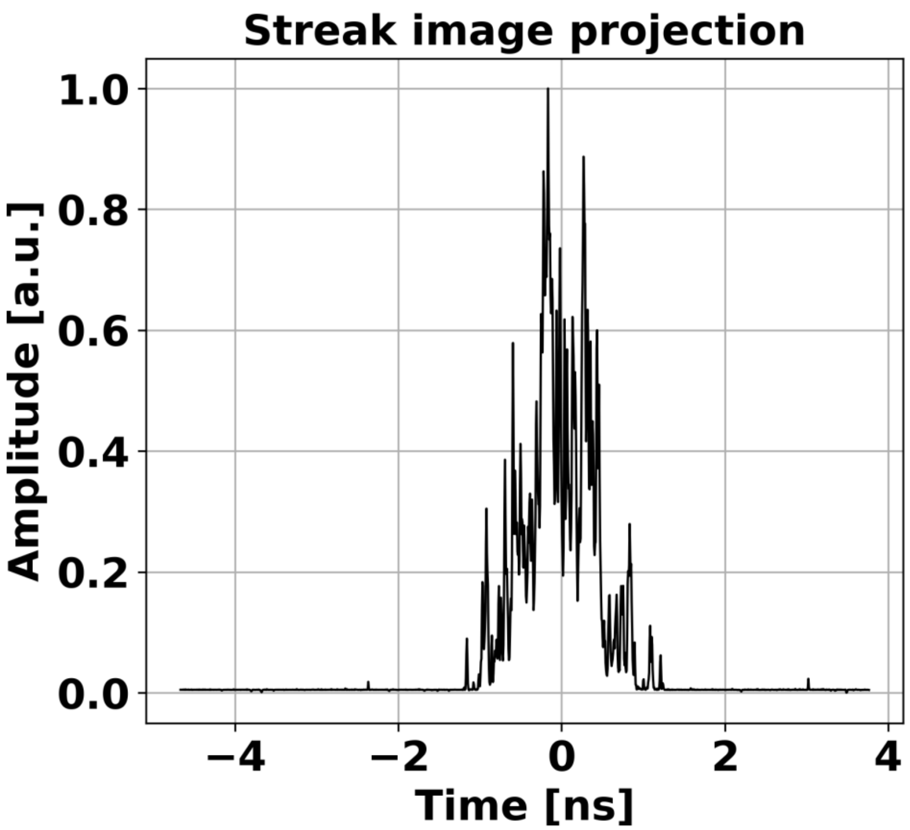
$$g_{\mathrm{obs}}(t) = h_{\mathrm{spot}}(t) * f_{\mathrm{signal}}(t)$$

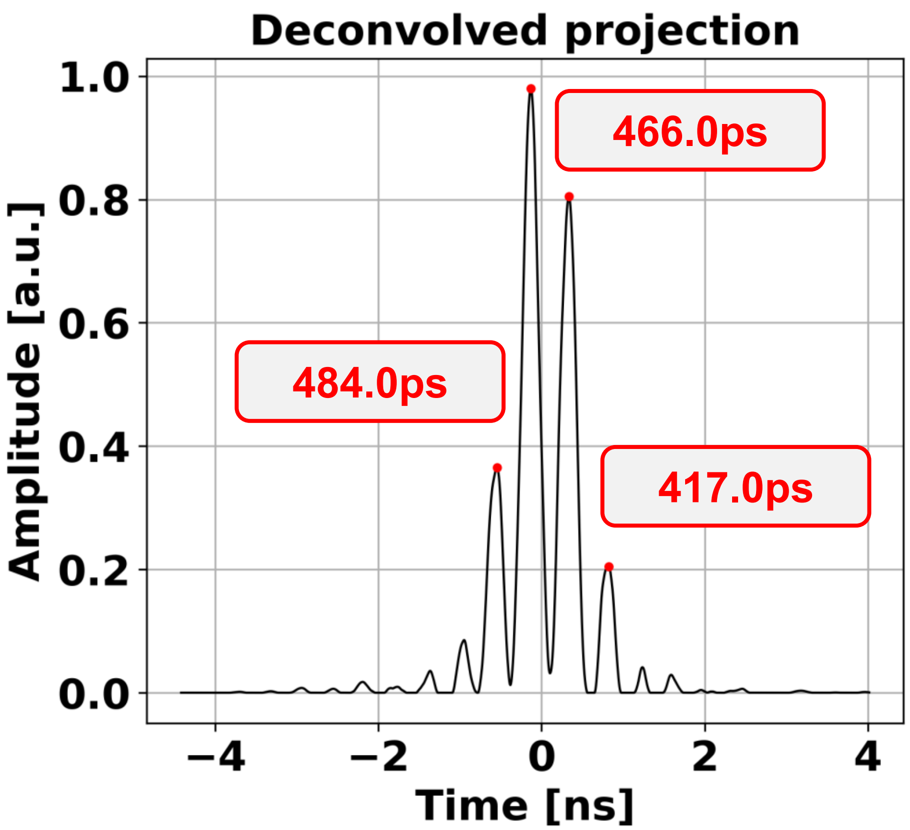




Deconvolution: 130pC, 105um, 0.10NA fiber

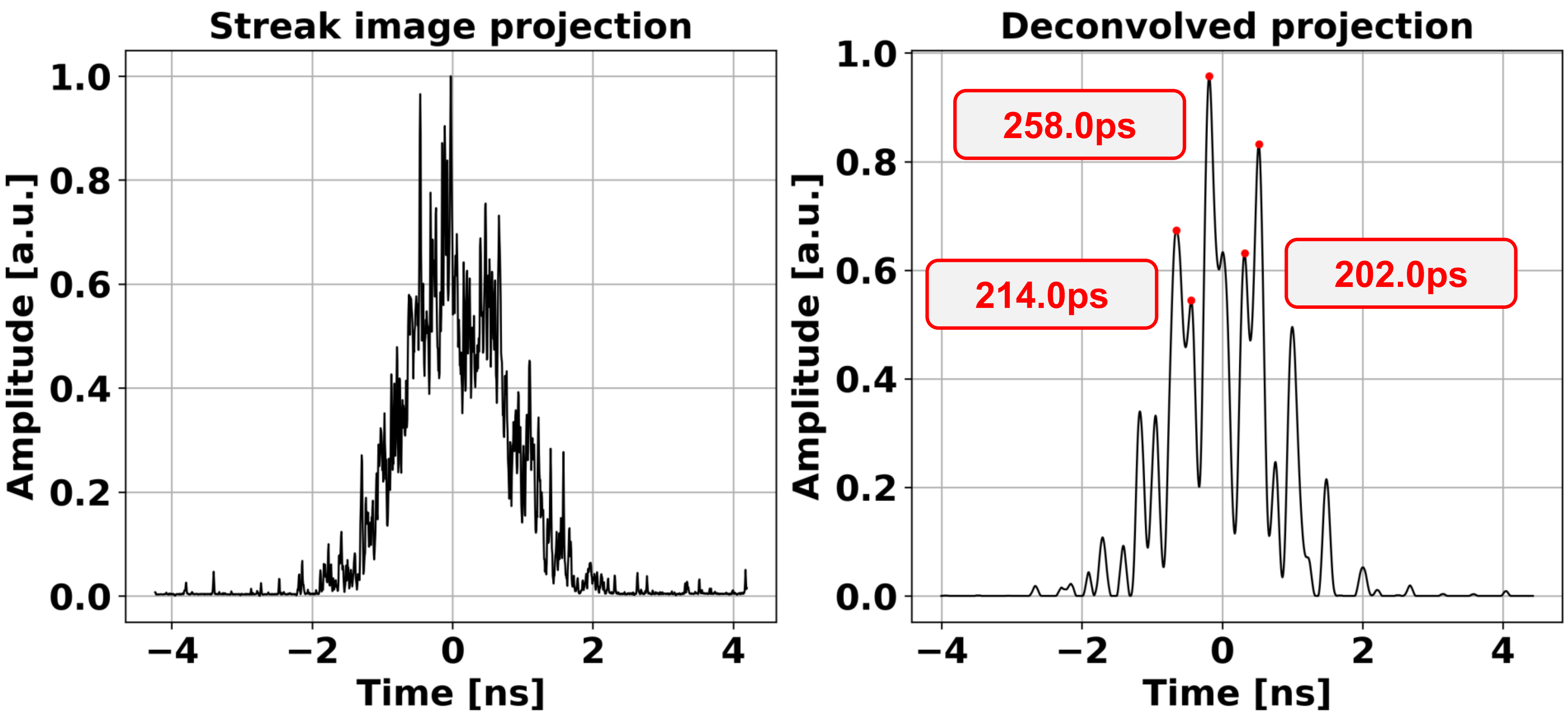
$$g_{\mathrm{obs}}(t) = h_{\mathrm{spot}}(t) * f_{\mathrm{signal}}(t)$$





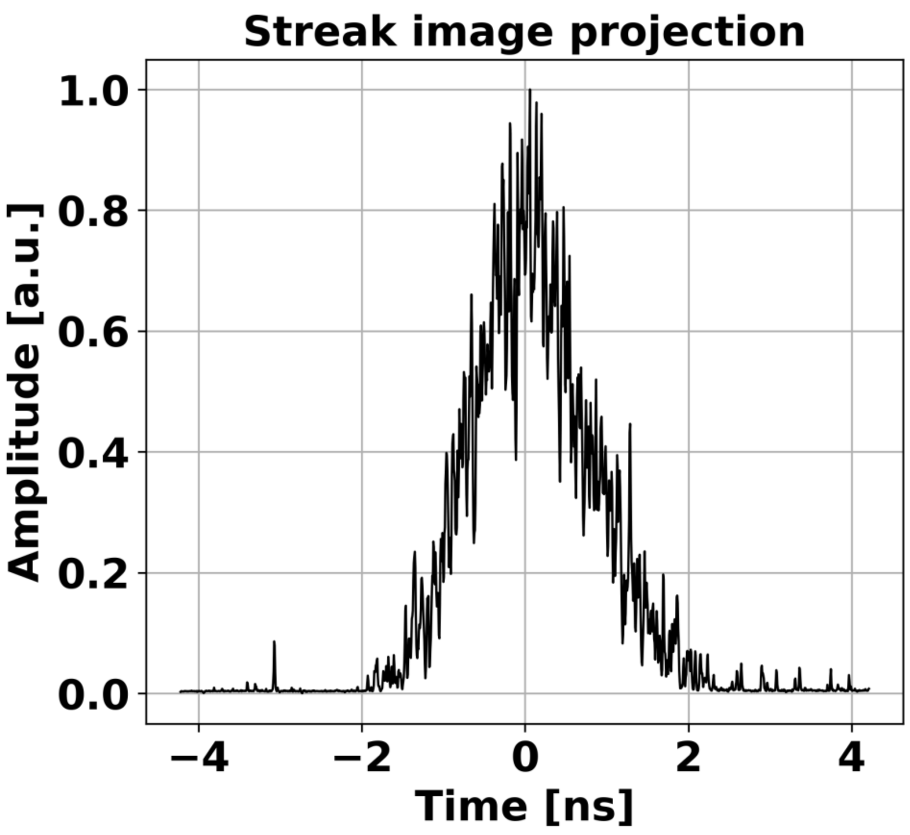
Deconvolution: 1nC, Photonic Lantern

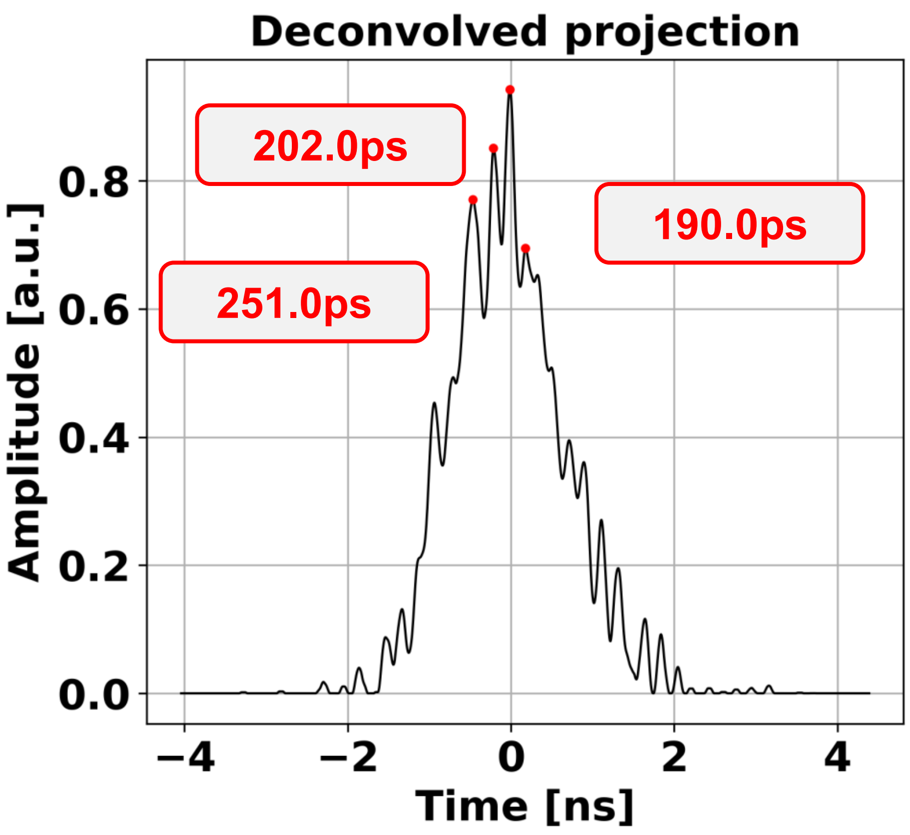
$$g_{\mathrm{obs}}(t) = h_{\mathrm{spot}}(t) * f_{\mathrm{signal}}(t)$$



Deconvolution: 1nC, Photonic Lantern

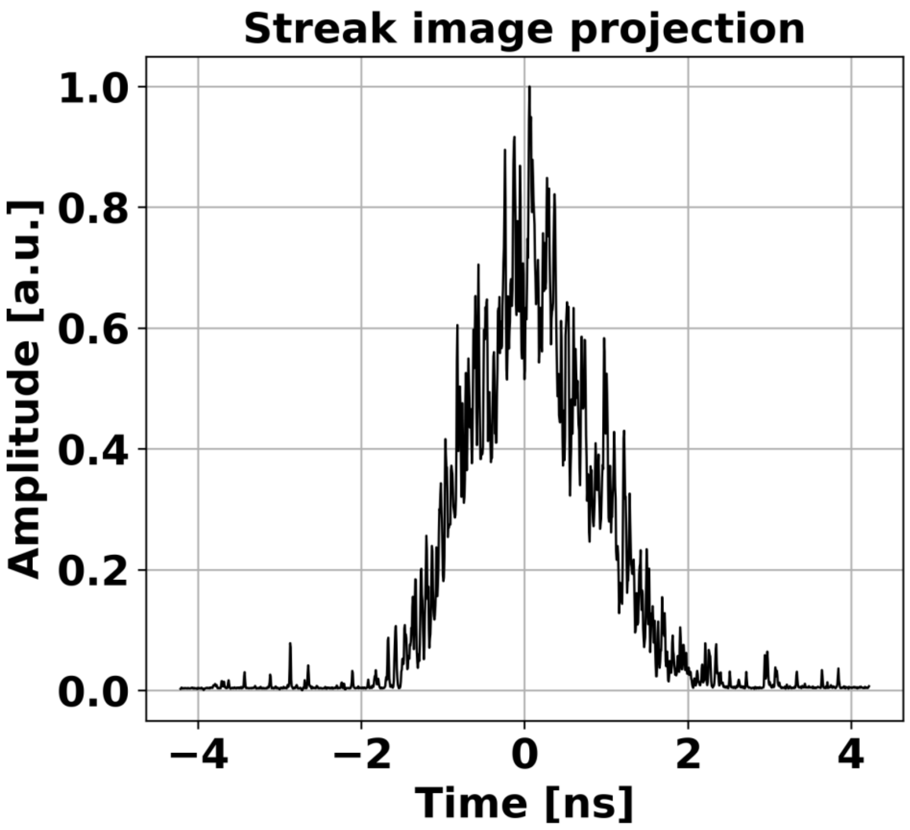
$$g_{\mathrm{obs}}(t) = h_{\mathrm{spot}}(t) * f_{\mathrm{signal}}(t)$$

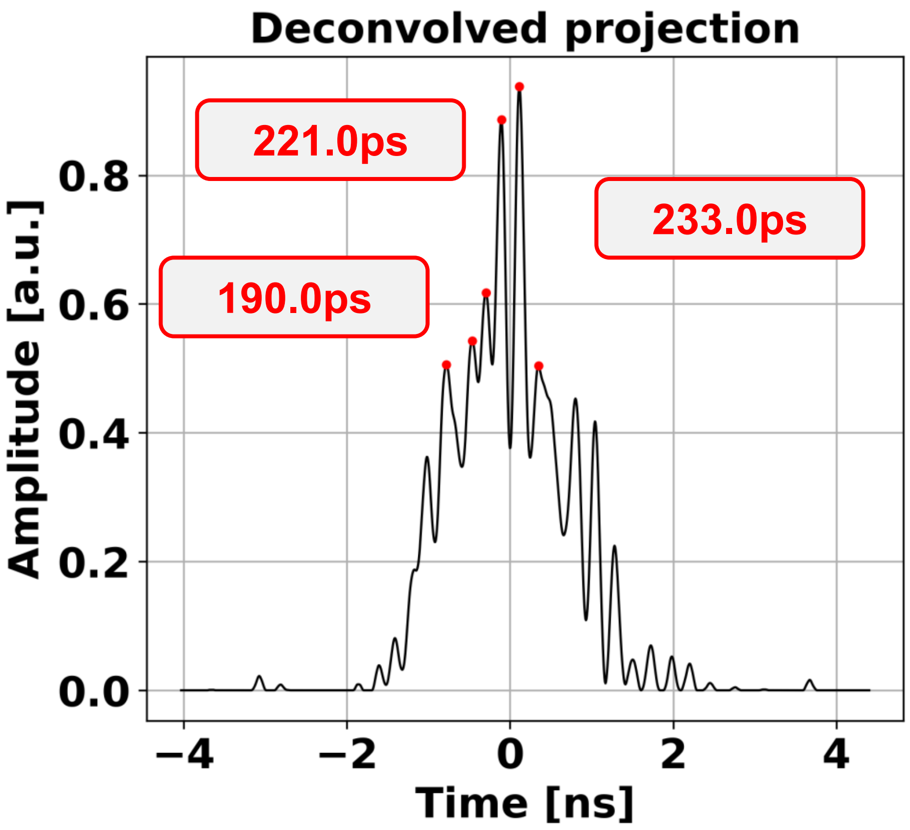




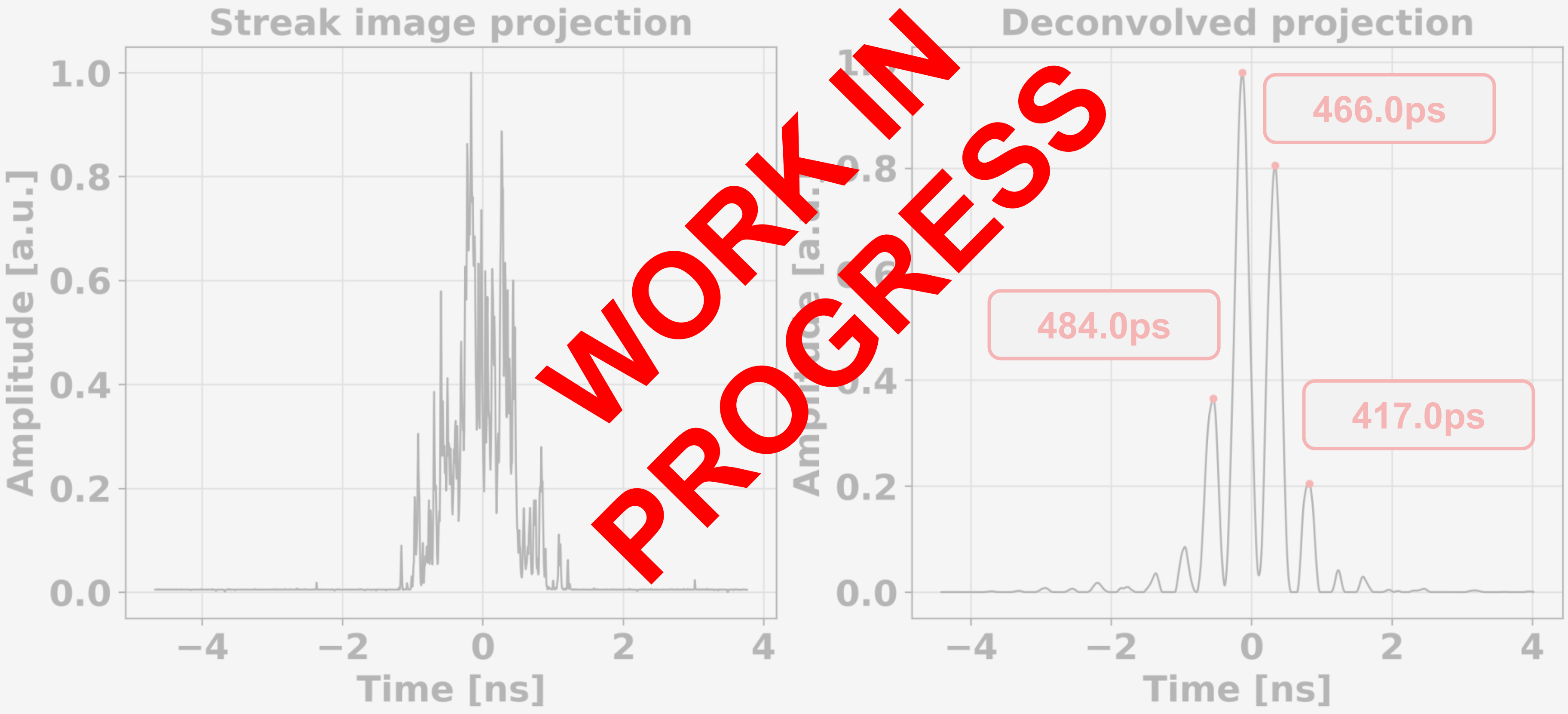
Deconvolution: 1nC, Photonic Lantern

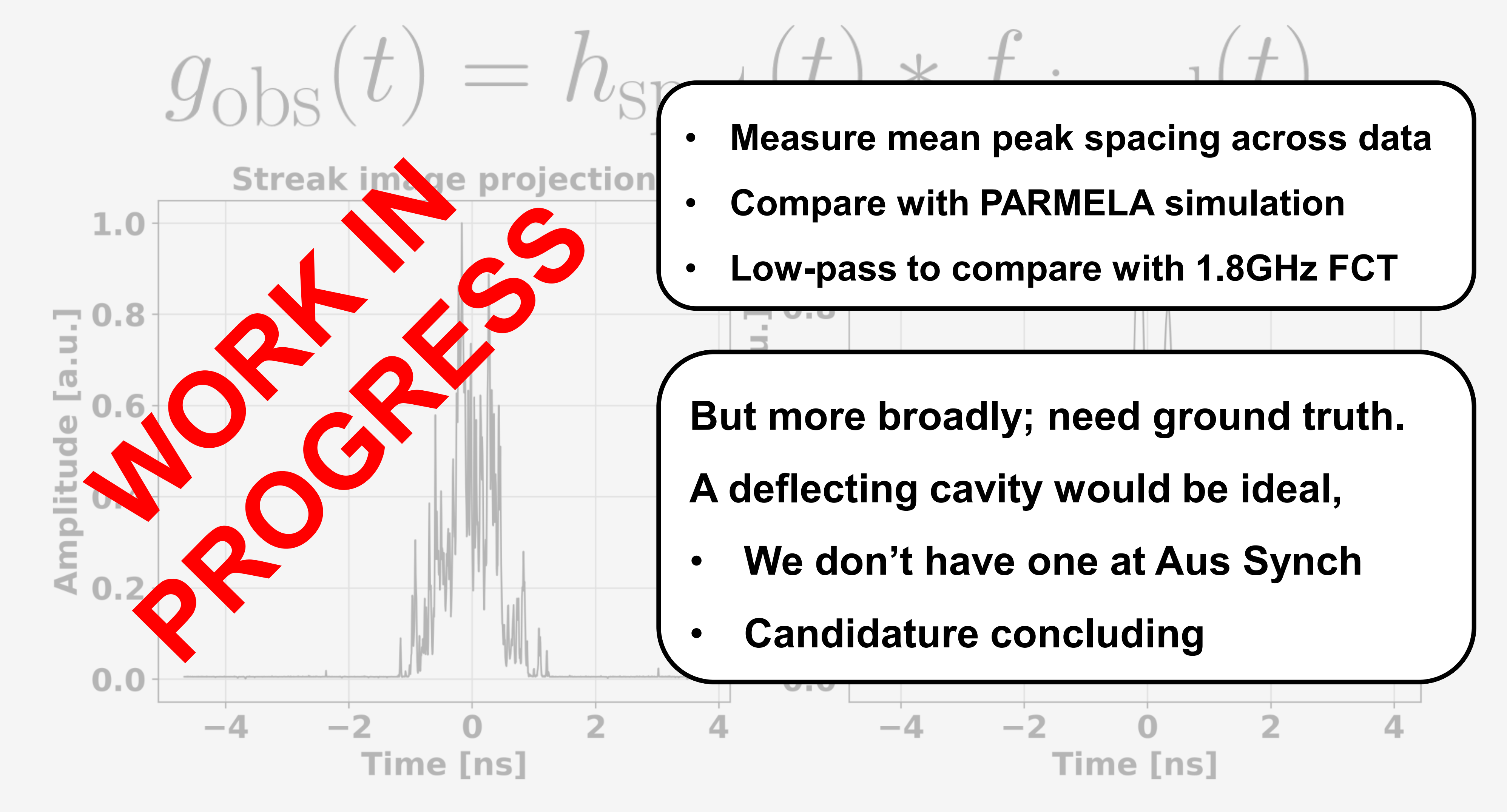
$$g_{\mathrm{obs}}(t) = h_{\mathrm{spot}}(t) * f_{\mathrm{signal}}(t)$$





$$g_{\rm obs}(t) = h_{\rm spot}(t) * f_{\rm signal}(t)$$





WORK IN PROGRESS

- Measure mean peak spacing across data
- Compare with PARMELA simulation
- Low-pass to compare with 1.8GHz FCT

But more broadly; need ground truth.

A deflecting cavity would be ideal,

- We don’t have one at Aus Synch
- Candidature concluding

Where did we end up?

<u>In single-shot and in-air:</u>

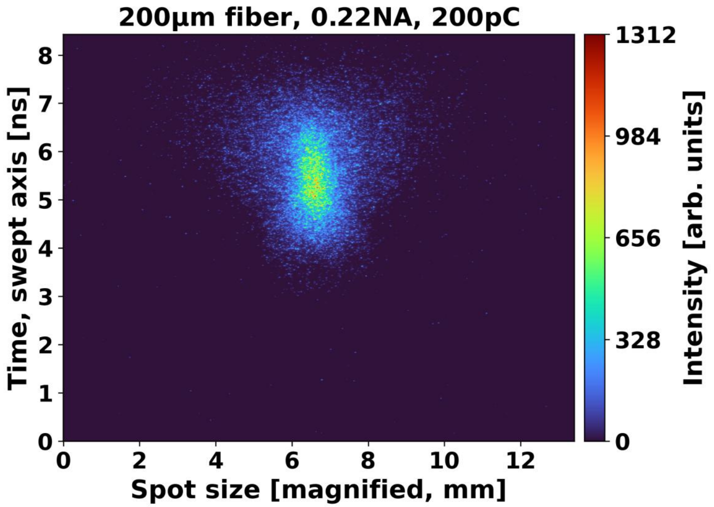
- **We generated ChR in MM fibers**
- **Transported ChR outside tunnel with fiber**
- **Detected ChR above streak cam noise floor**

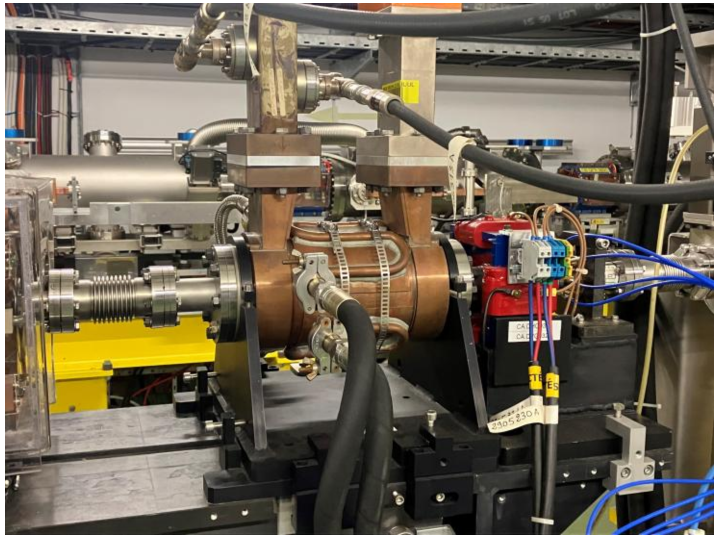
<u>But lanterns require accumulation.</u>

- **First successful irradiation of a lantern**

<u>With streak camera PSF deconvolution:</u>

- **We (*maybe*) measure micro-bunch spacing**



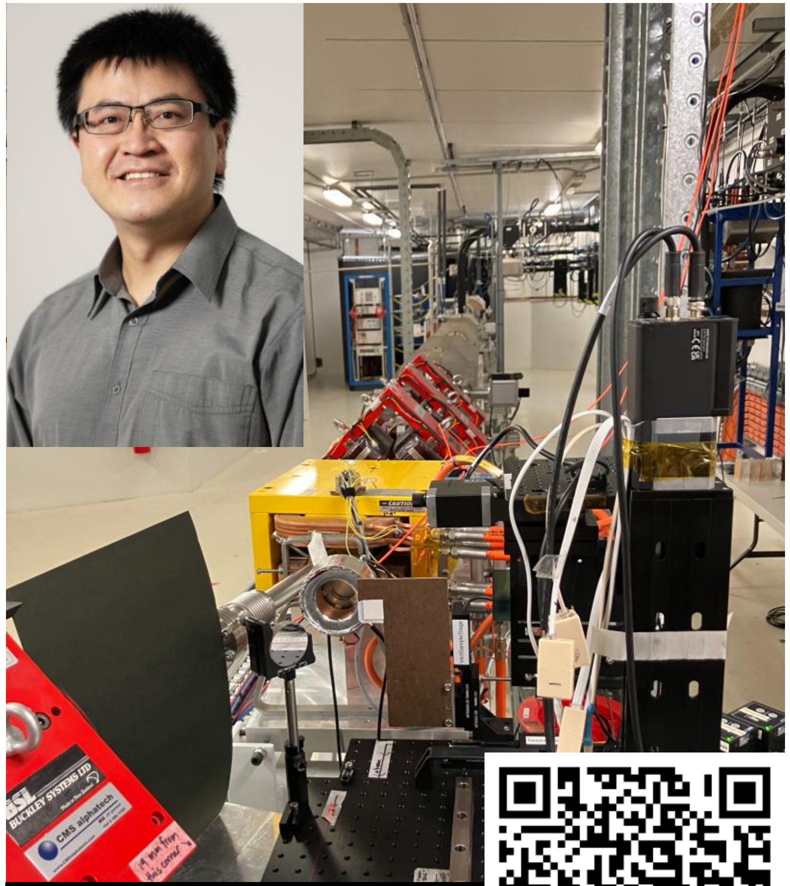


Acknowledgements

Left to right: Prof. Sergio Leon-Saval, Jin (Fiona) Wei (PhD student), Dr. Andrew Ross-Adam, Dr Christopher Betters.

SAIL
SYDNEY ASTROPHOTONIC INSTRUMENTATION LABORATORY

Contact:
Professor Sergio Leon-Saval
Email: sergio.leon-saval@sydney.edu.au
Dr Christopher Betters
Email: christopher.betters@sydney.edu.au



Contact:
Eugene Tan
yawrent@ansto.gov.au

A big thank you to the University of Melbourne Accelerator Physics group, and operations team at Australian Synchrotron!