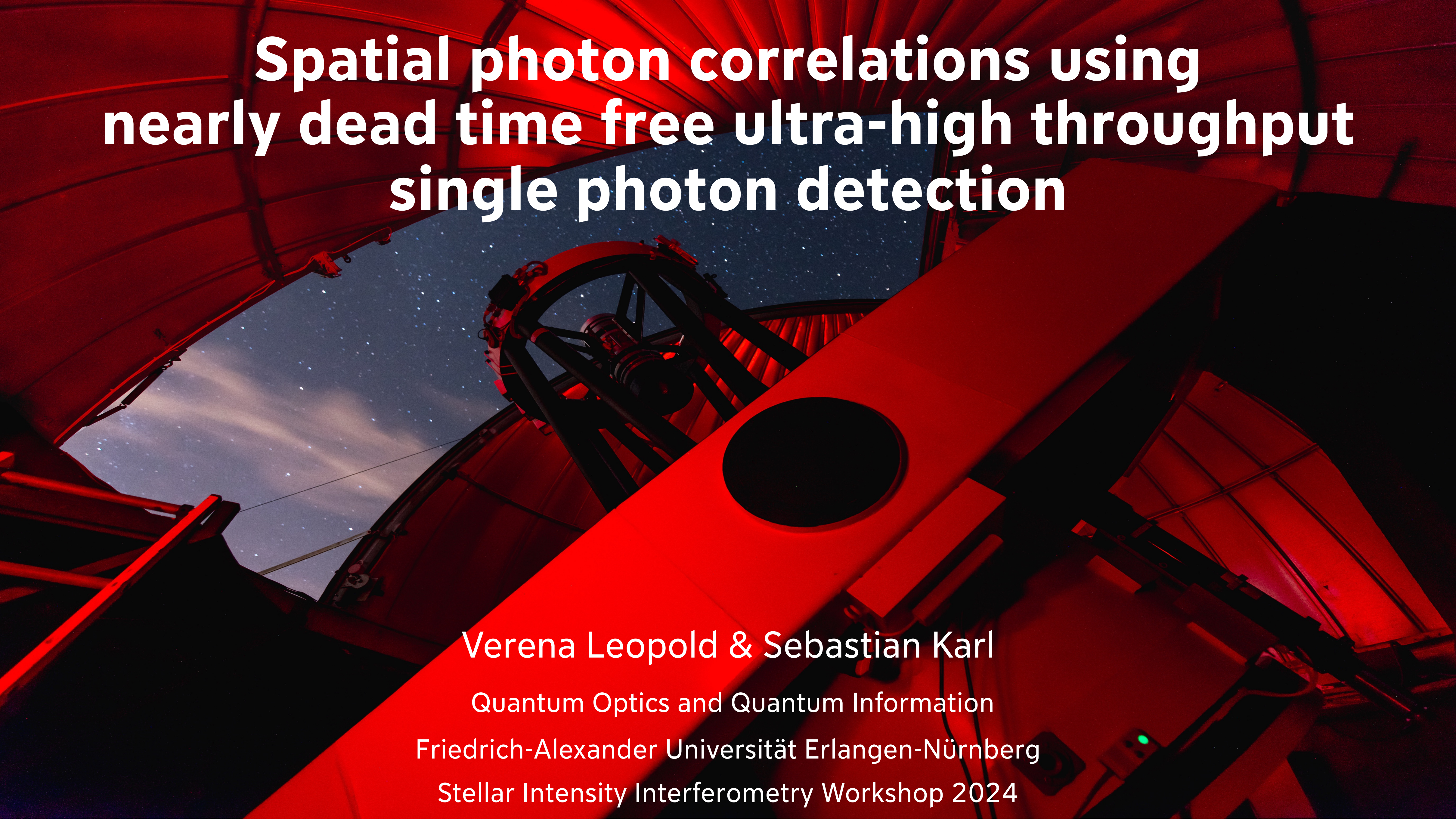


Spatial photon correlations using nearly dead time free ultra-high throughput single photon detection

Verena Leopold & Sebastian Karl

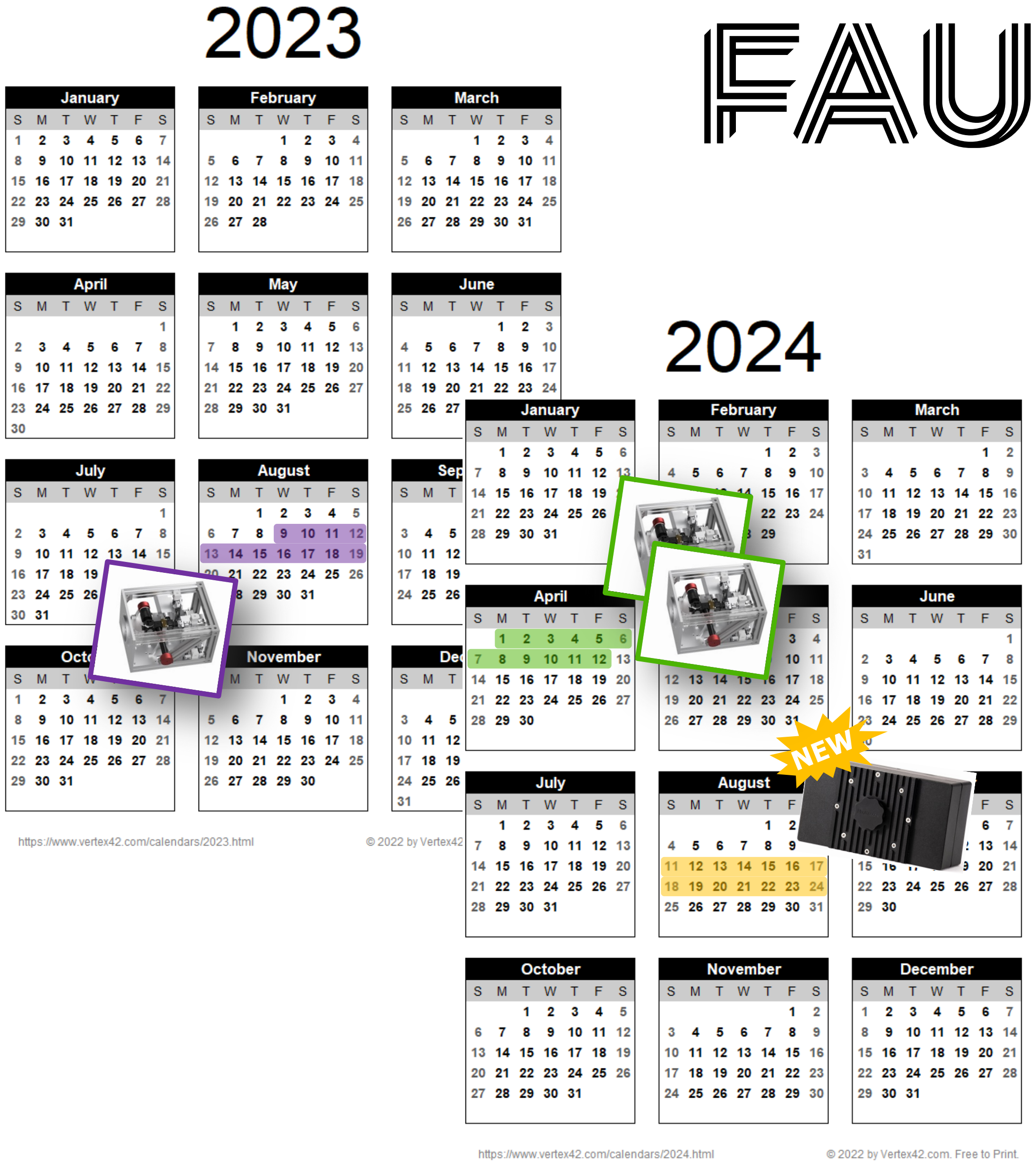
Quantum Optics and Quantum Information

Friedrich-Alexander Universität Erlangen-Nürnberg

Stellar Intensity Interferometry Workshop 2024

Agenda

1. Introduction
2. Measurement Setup
3. Temporal Correlations at C2PU
4. The Problem of moving Stars
5. Spatial Correlations using HPDs
6. High Throughput System (HTS)
7. Spatial Correlations using HTS
8. Summary and Outlook



Introduction

Motivation

- Larger telescopes increase SNR in HBT measurements
- For bright stars: hybrid single photon detectors saturate for telescopes > 1m
- For spatial correlations ordered timestream is necessary
- Manageable data rate

Solutions:

1) Use new kind of detector
2) Find Synchronization hardware
3) Use high throughput TDC

Telescope Site

The Calern observatory is located in the South of France close to Nice on a plateau with an altitude of 1270m. C2PU offers twin telescopes at a seperation of 15m.

- Primary mirror diameter of 1.04 m
- Equatorial yoke mount
- Cassegrain secondary focus
- Focal length of 13m and F/12.5

06°55'23" East
43°45'13" North

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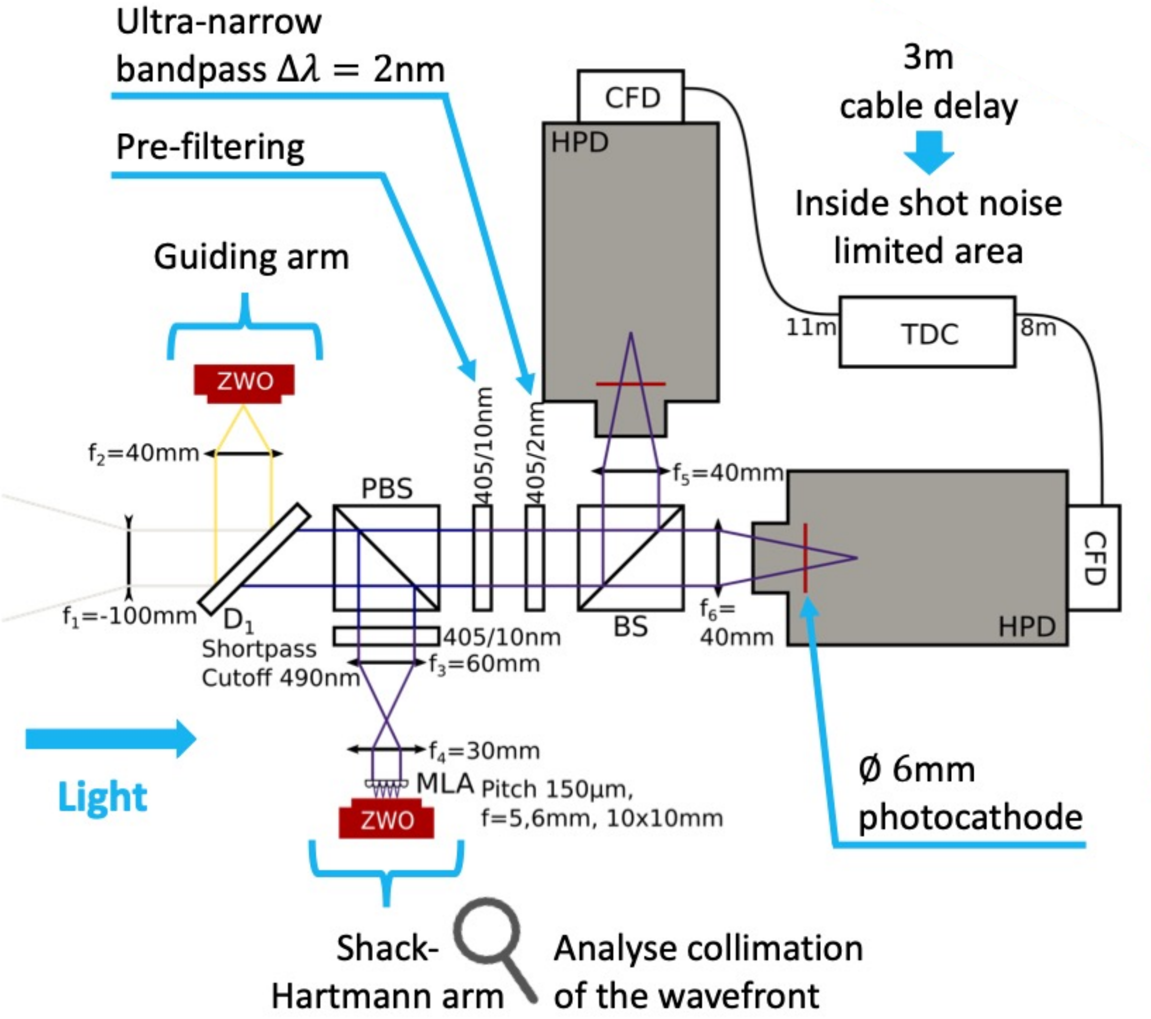
East Dome
Epsilon

Omicron
West Dome

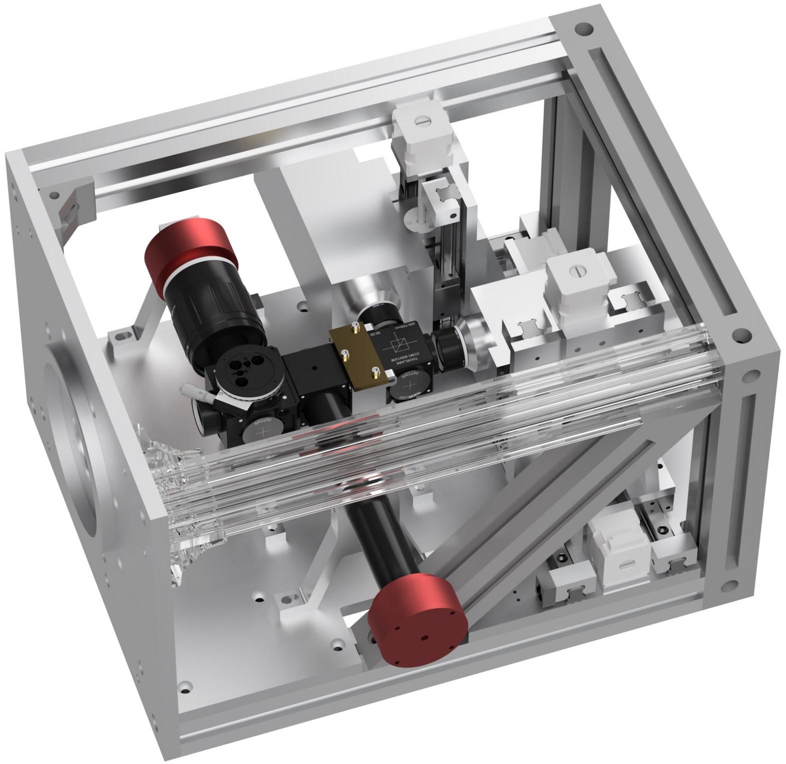
Measurement Setup

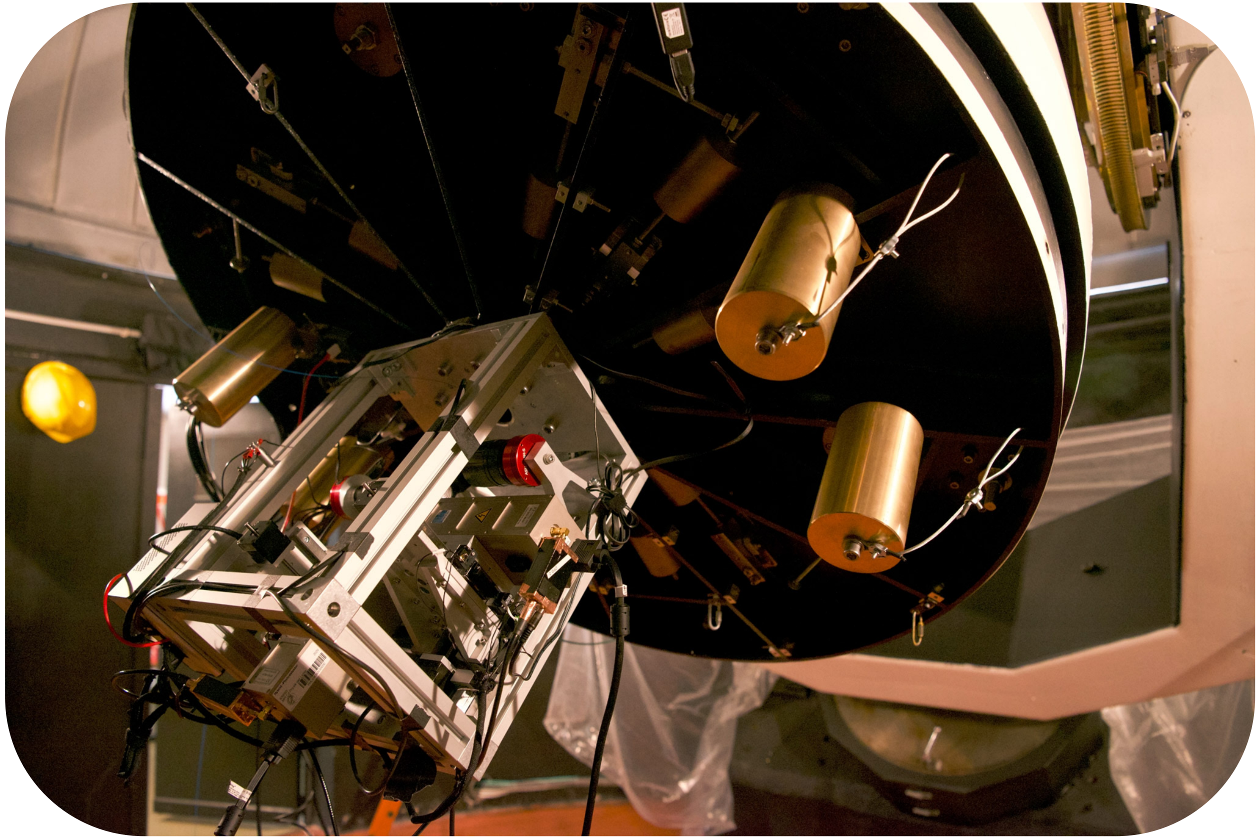
Optical Setup



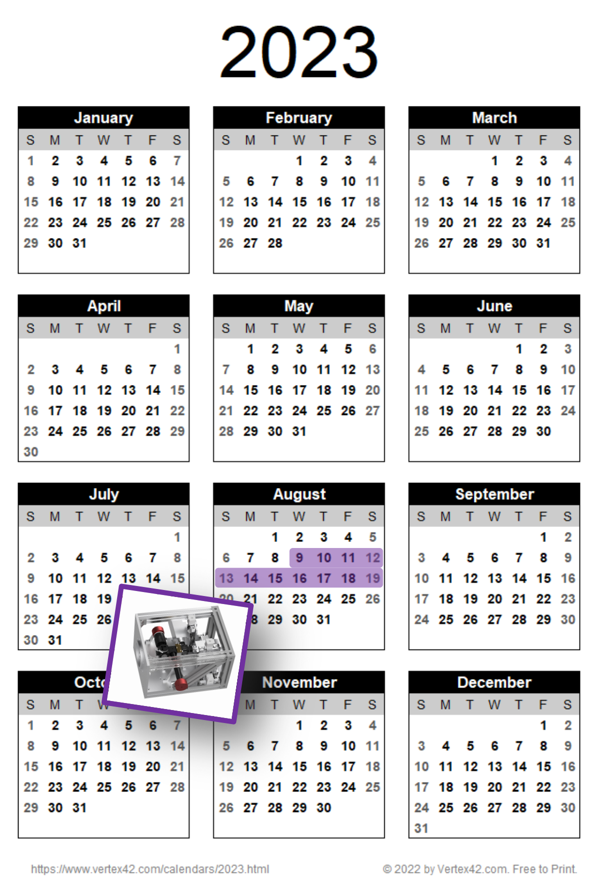
- 40/45mm lenses for beam compression (no focus)
- Used for all three measurements
- TDC and detectors will change
- Cable delays will vary from 3 to 12m

Measurement Setup

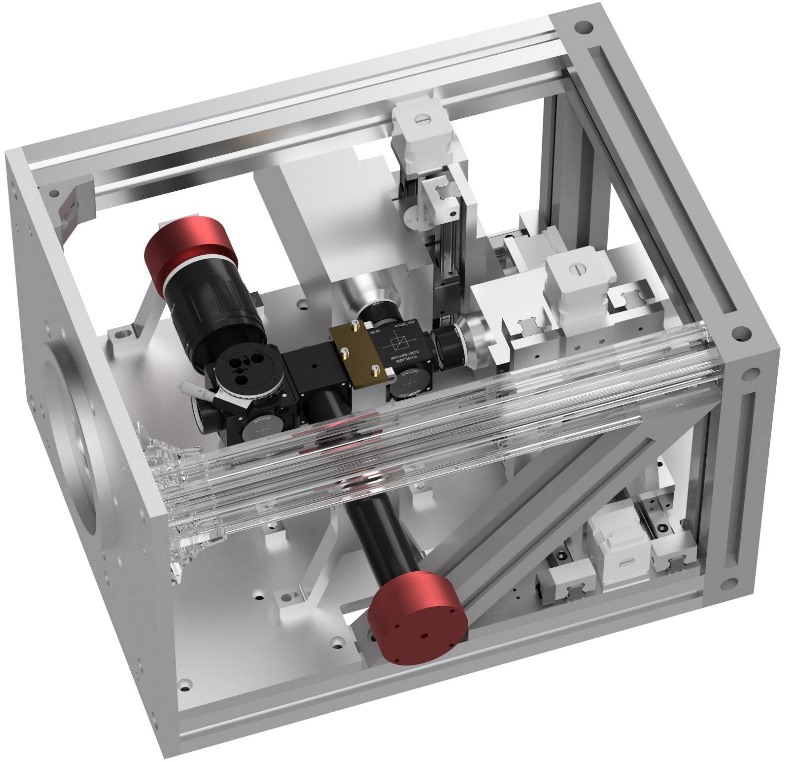


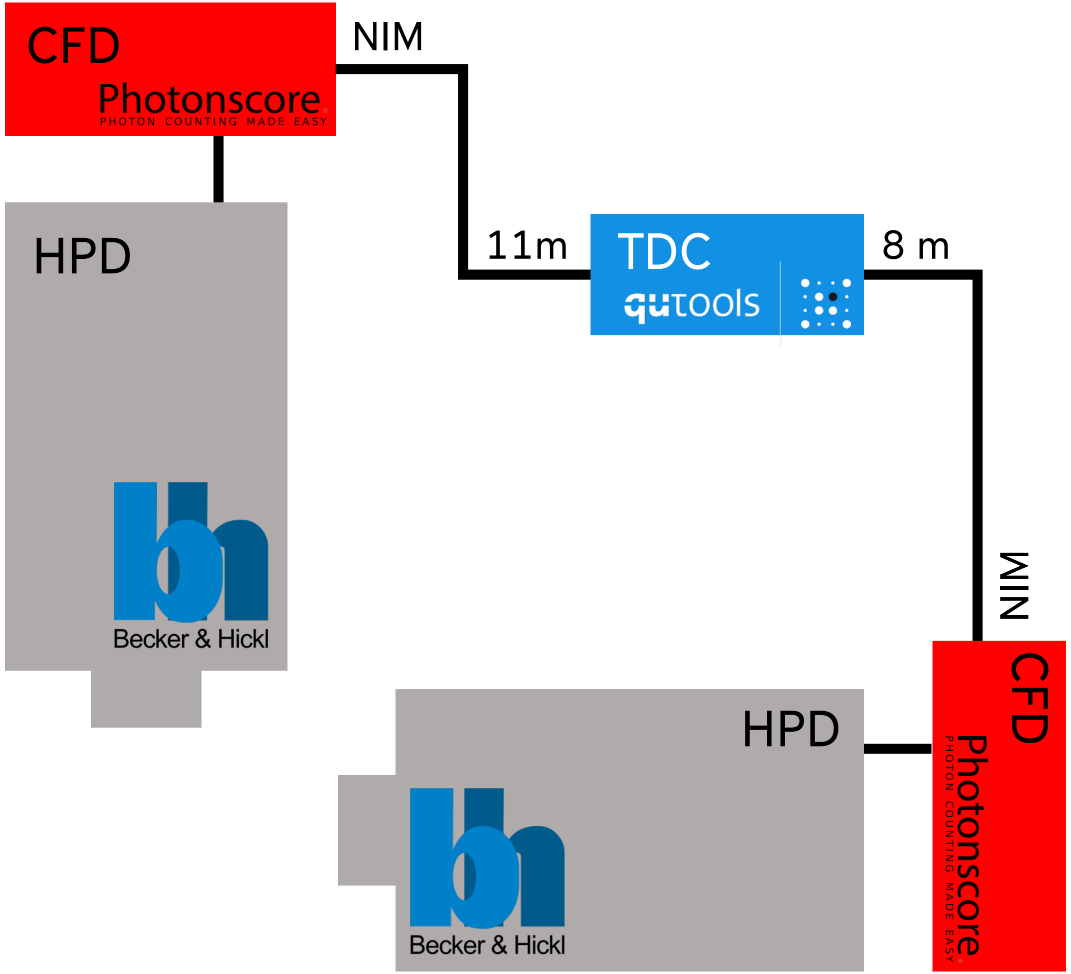


Temporal Correlations at C2PU



Measurement Configuration





Hybrid Photon Detectors (HPDs)

- HPM-100-06 from Becker&Hickl
- Hamamatsu R10467 hybrid detector tube
- Ø6mm active area
- Max. continuous countrate 10MHz
- 100 - 400Hz dark counts
- Quantum efficiency of 22.7% at 405nm
- Output is not discriminated, puls height varies

Becker & Hickl

Hybrid Photon Detectors (HPDs)

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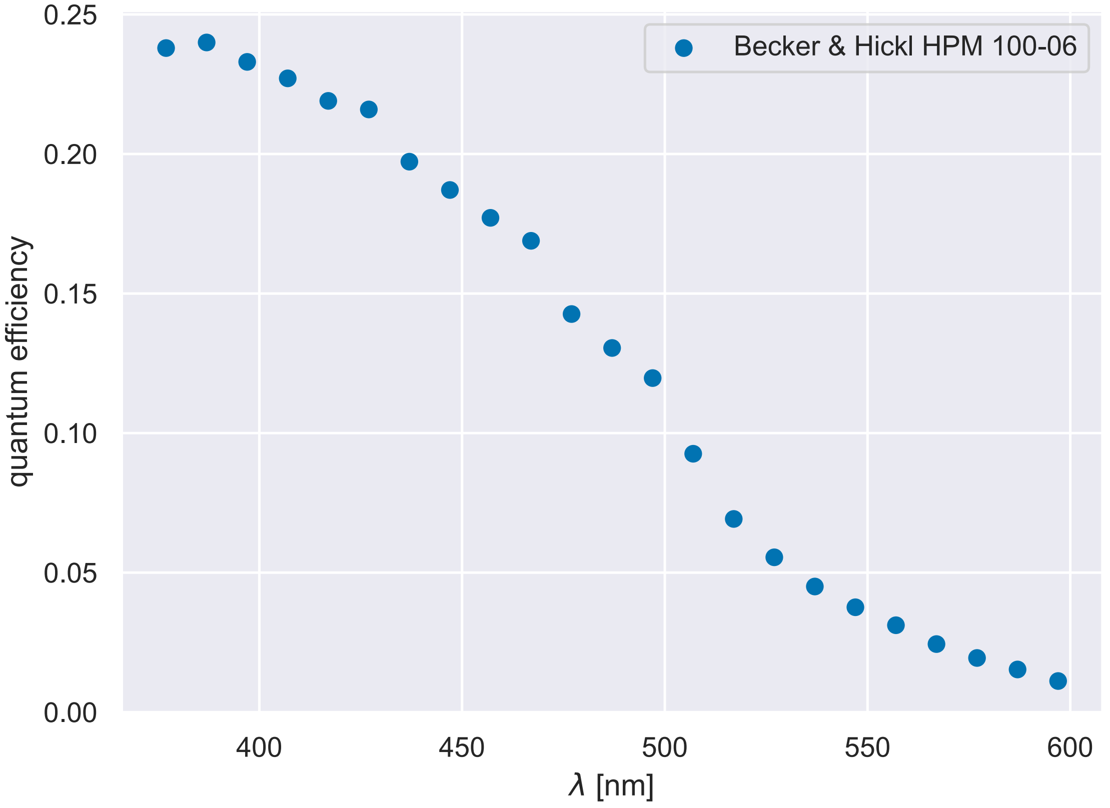
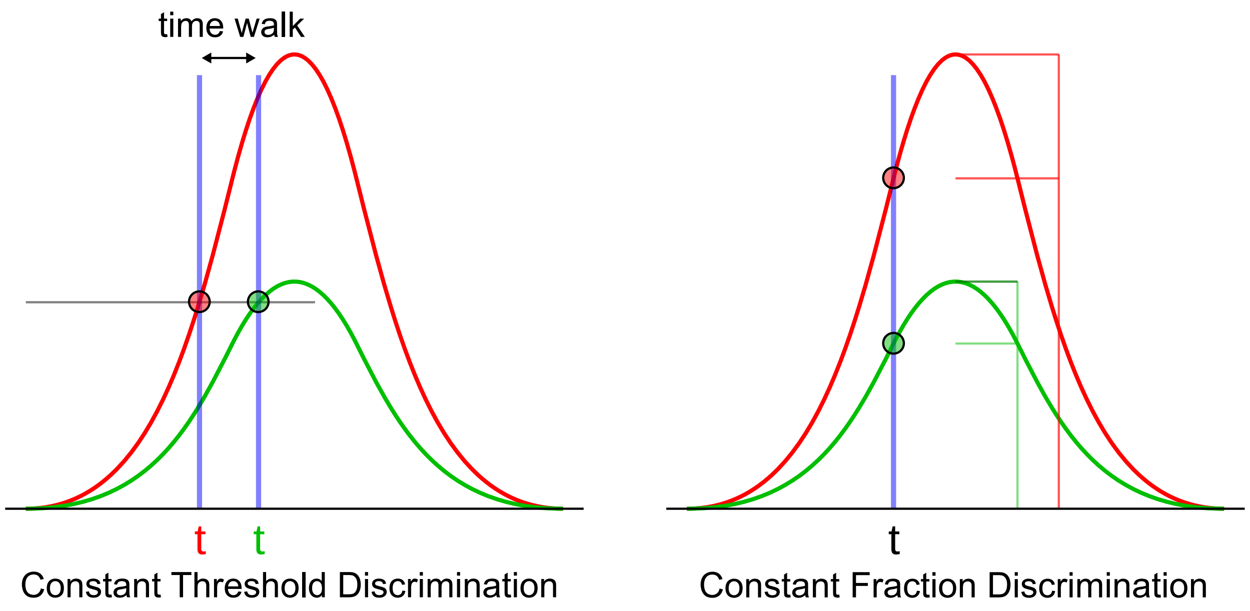
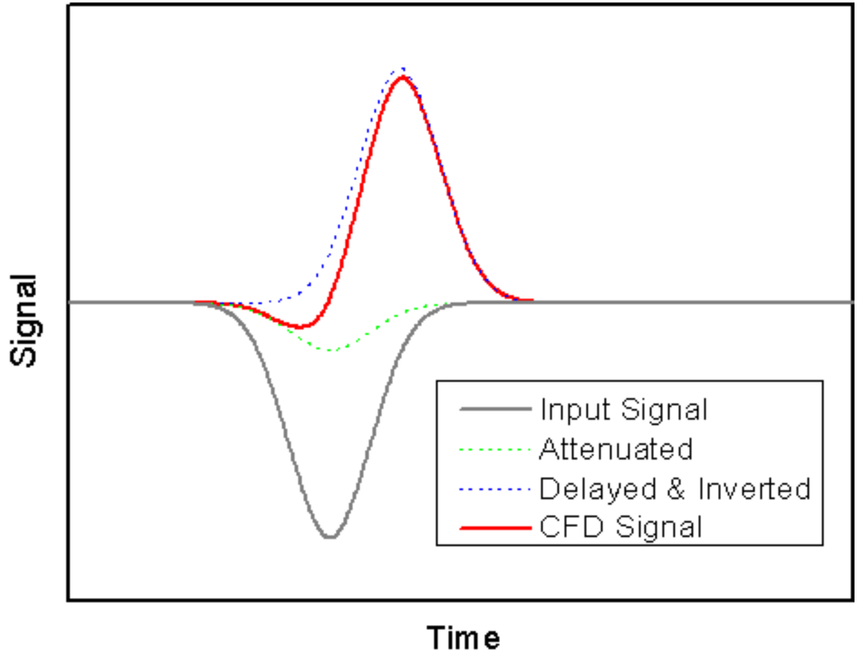


Constant Fraction Discriminator (CFD)



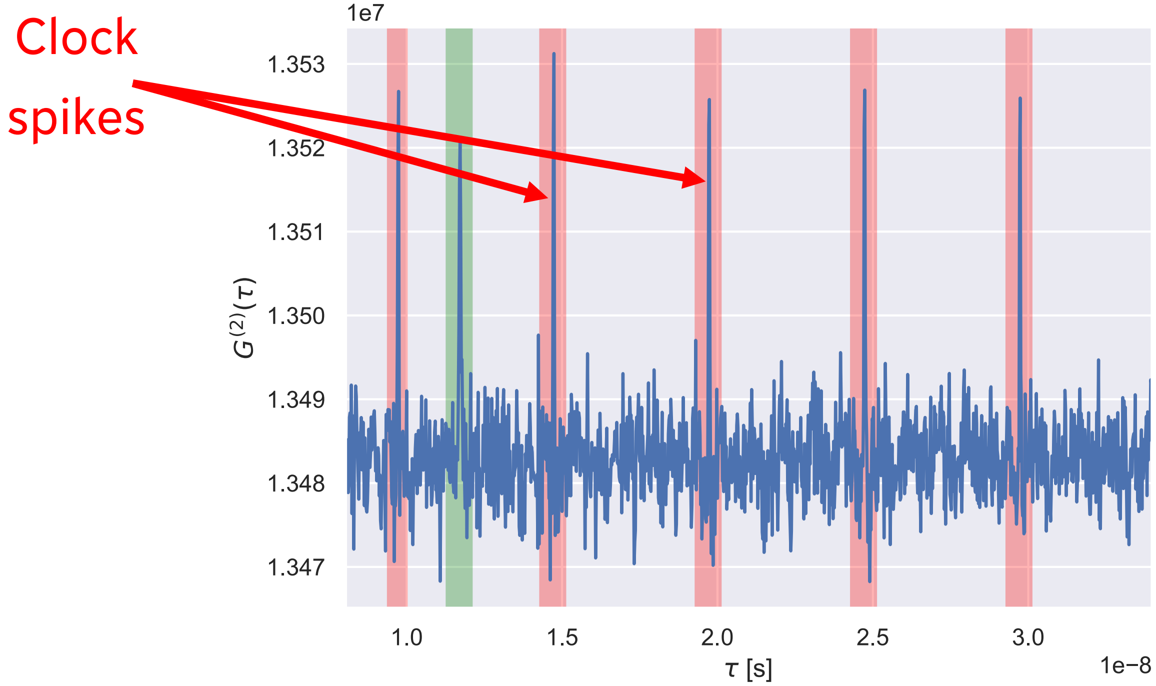


→ Use Constant Fraction instead of Constant Threshold Discriminator

→ Tune parameters *threshold* and *zero crossing*

quTools TDC

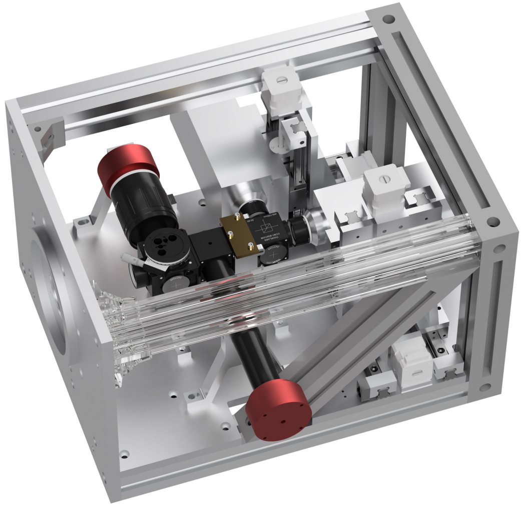
- 40ns deadtime
- maximal event rate per channel is limited to 25 Mcps



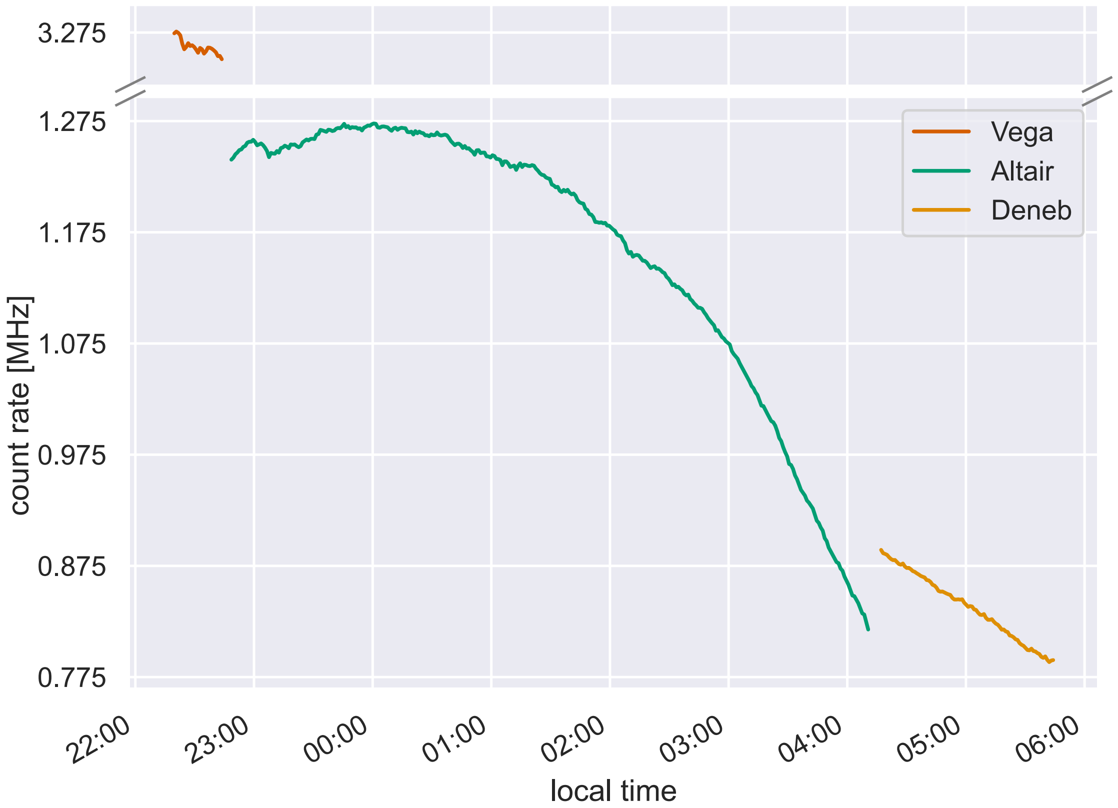
→ 3m cable difference needed to lie inside a shot noise limited area

Advantages of the Setup

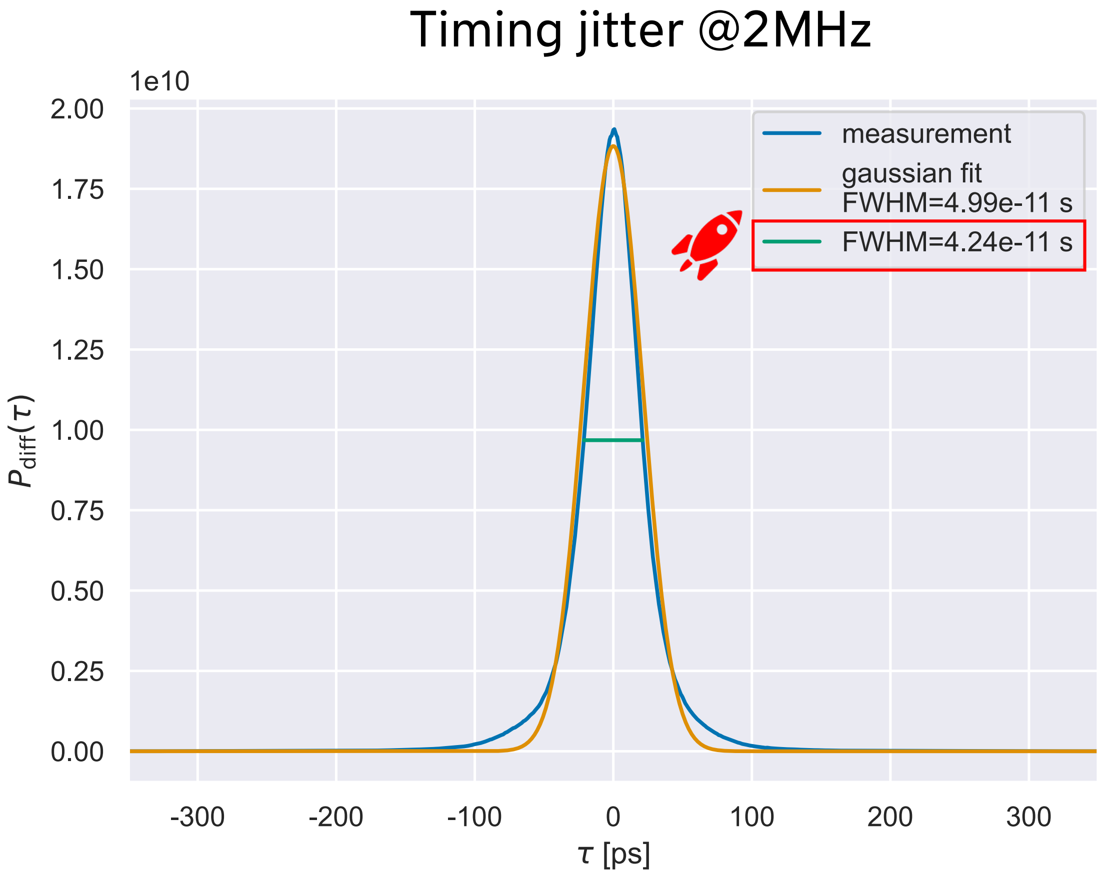
- Tracking of the star never lost
- Short optical path
- Observation in the blue at 405nm
- Easy to align at the telescope
- Movable detectors in x and y-direction



Typical Measurement Night

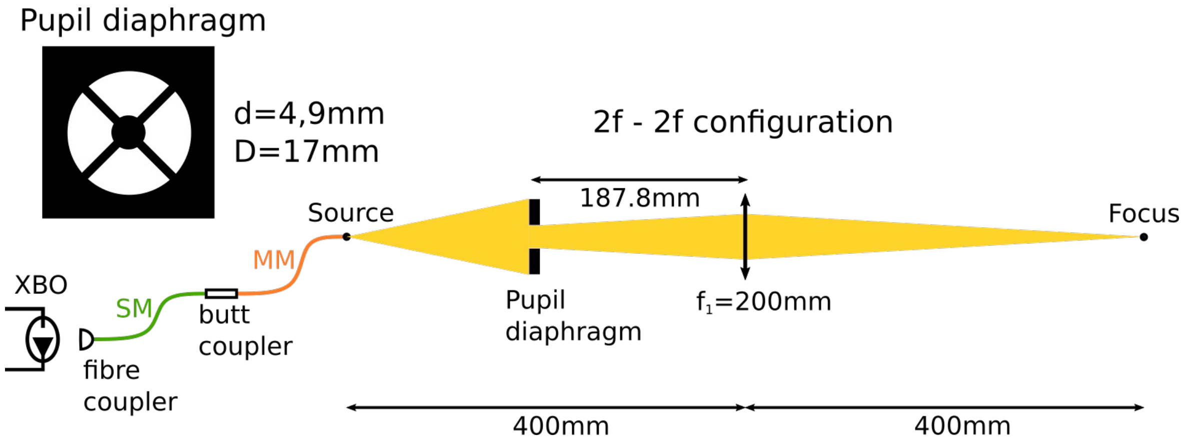


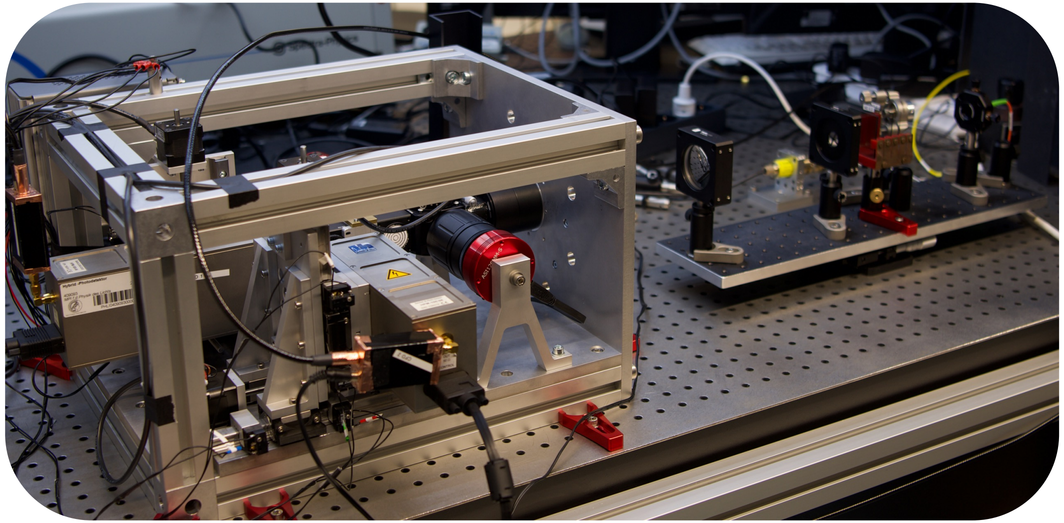
Timing resolution of the setup



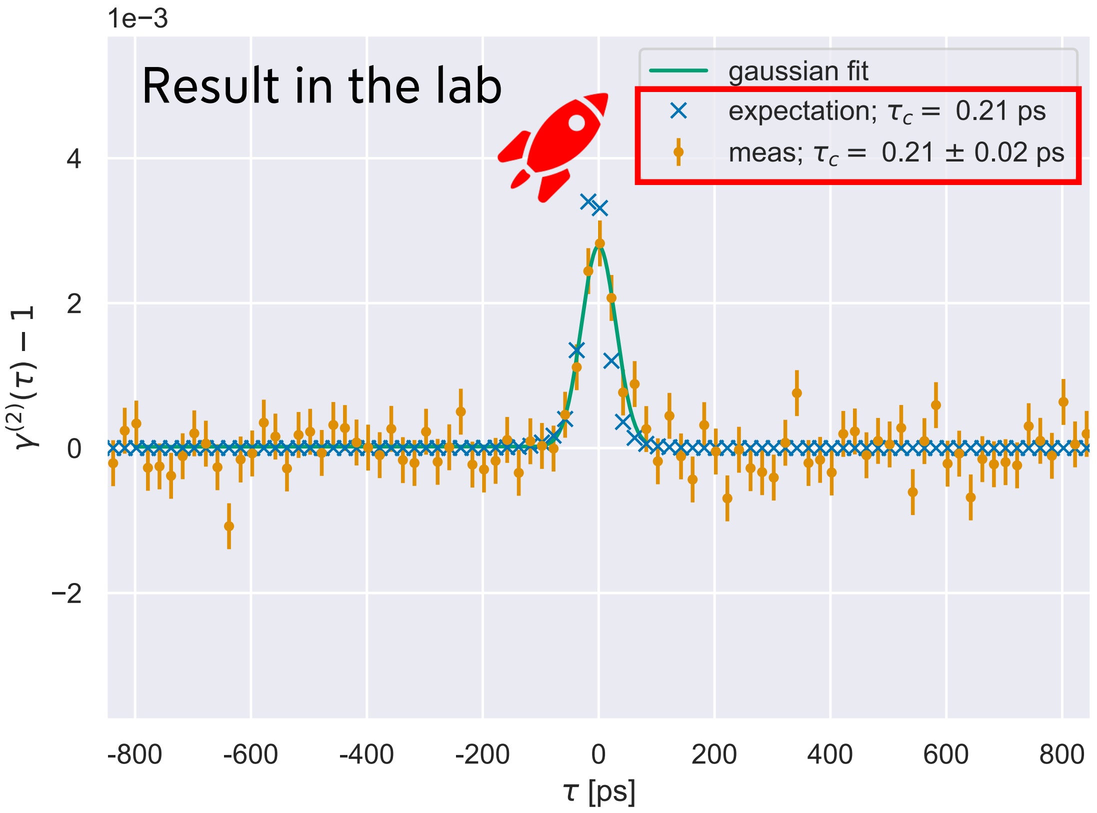
- 42.4ps timing jitter of the system using a fs-pulsed laser
- Full photo detection system of 2 HPDs, 2 CFDs and the quTAG, as well as one 50:50 non-polarizing beam splitter
- Result will be used to calculate the measurement expectations

Observe artificial star



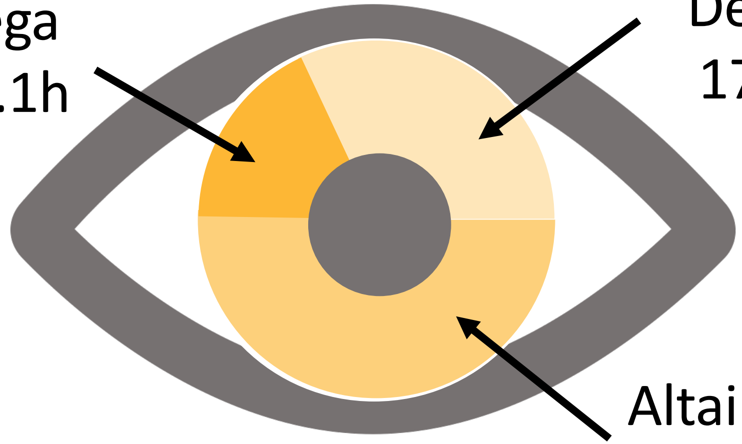


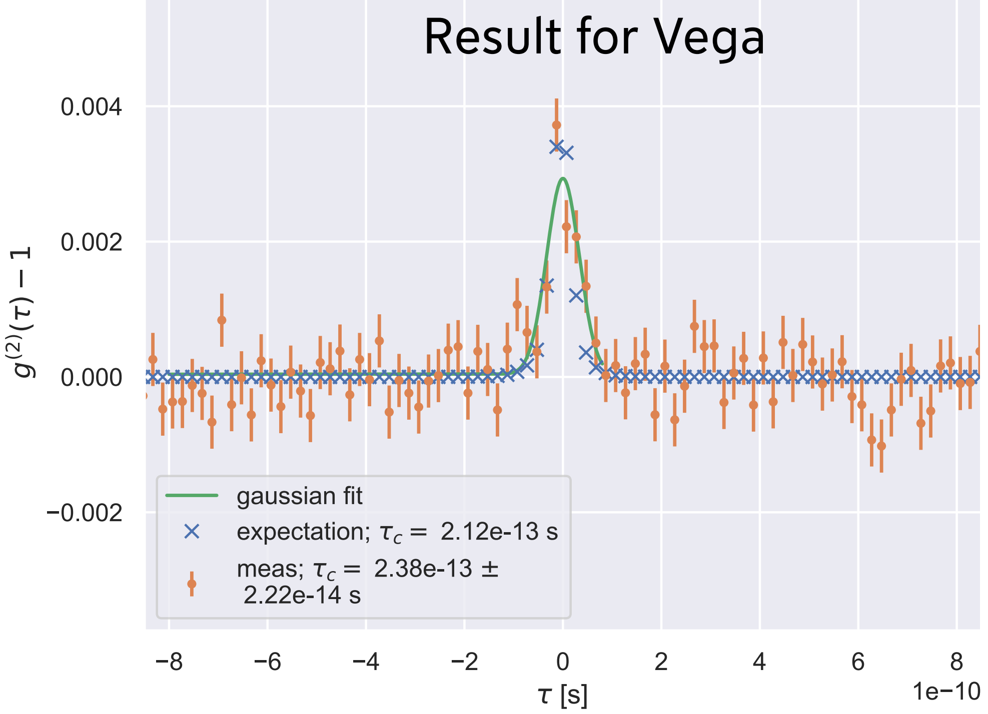
- Expected coherence time 0.21ps
- Measured coherence time with artificial star in the lab: 0.21 ± 0.02ps



Temporal Correlations at C2PU

Observation Time





App. Magnitude

Vega 0.026

Altair 0.76

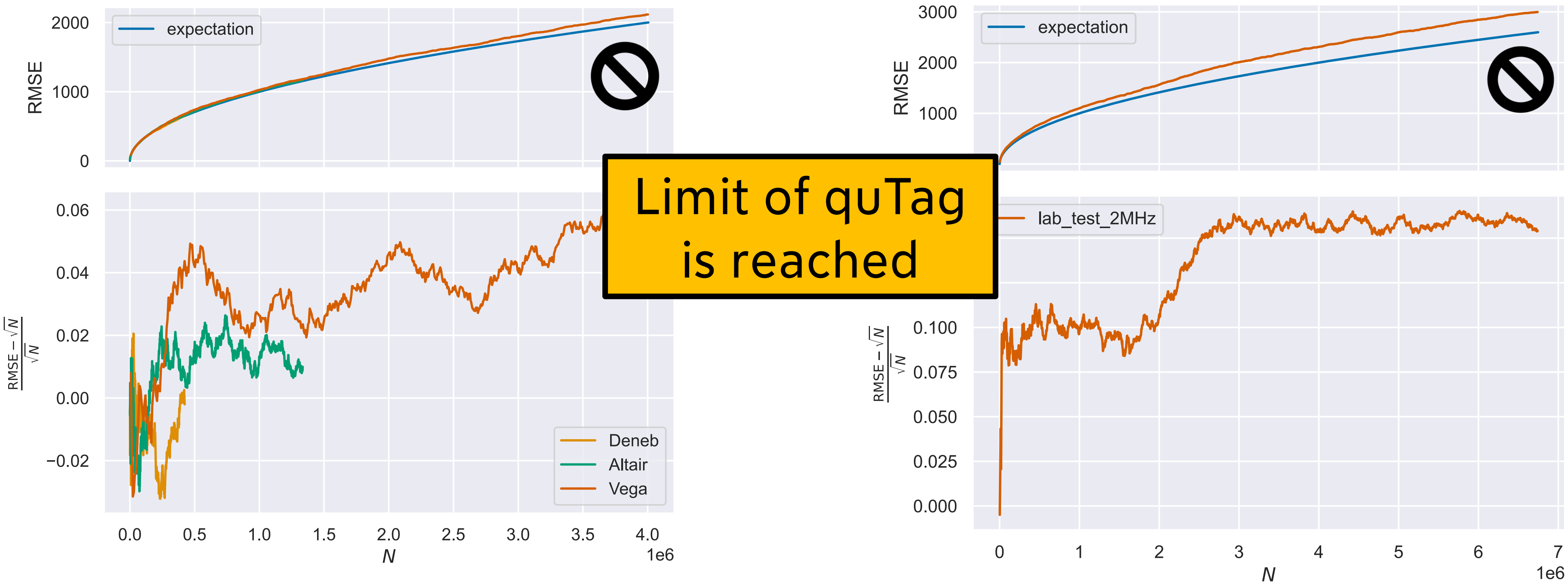
Deneb 1.25

Star	Meas. τ_c [ps]	SNR
Vega	0.238 ± 0.0222	10.72
Altair	0.217 ± 0.0350	6.20
Deneb	0.159 ± 0.0605	2.63

Limitations of the configuration

@Telescope

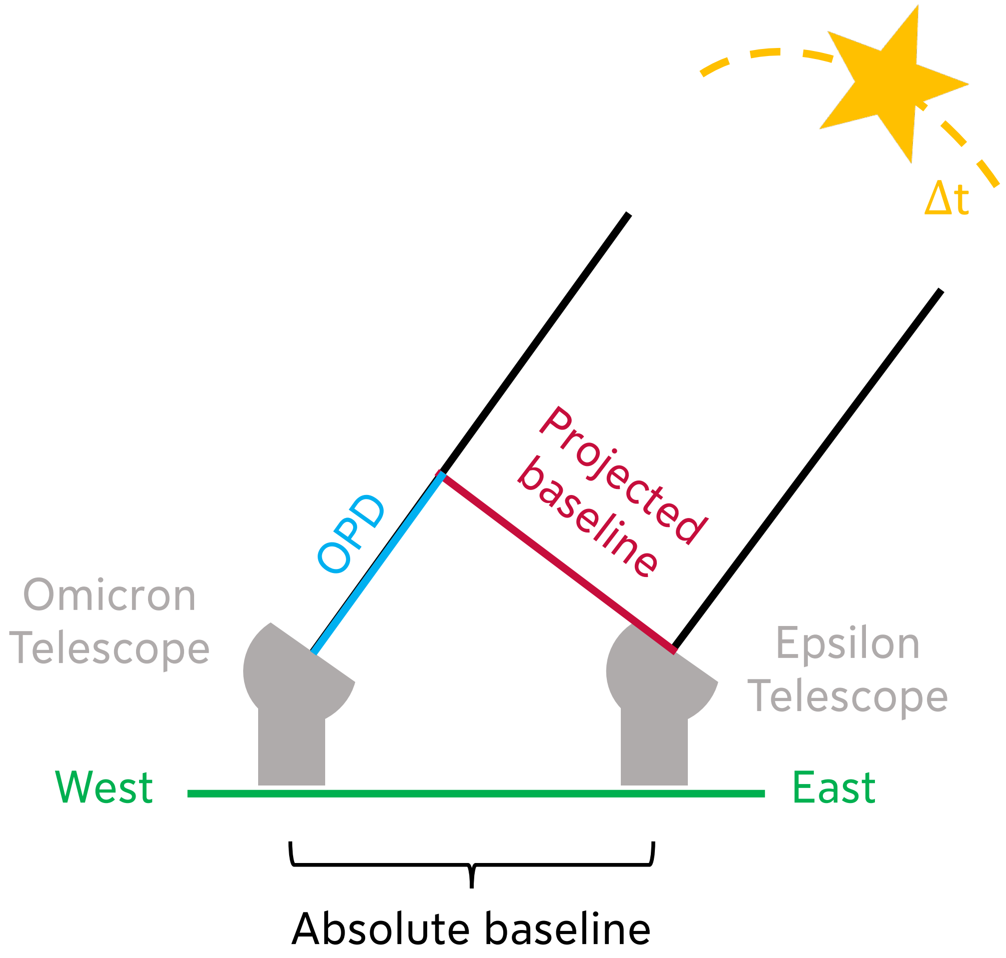
In the Lab



The Problem of moving Stars

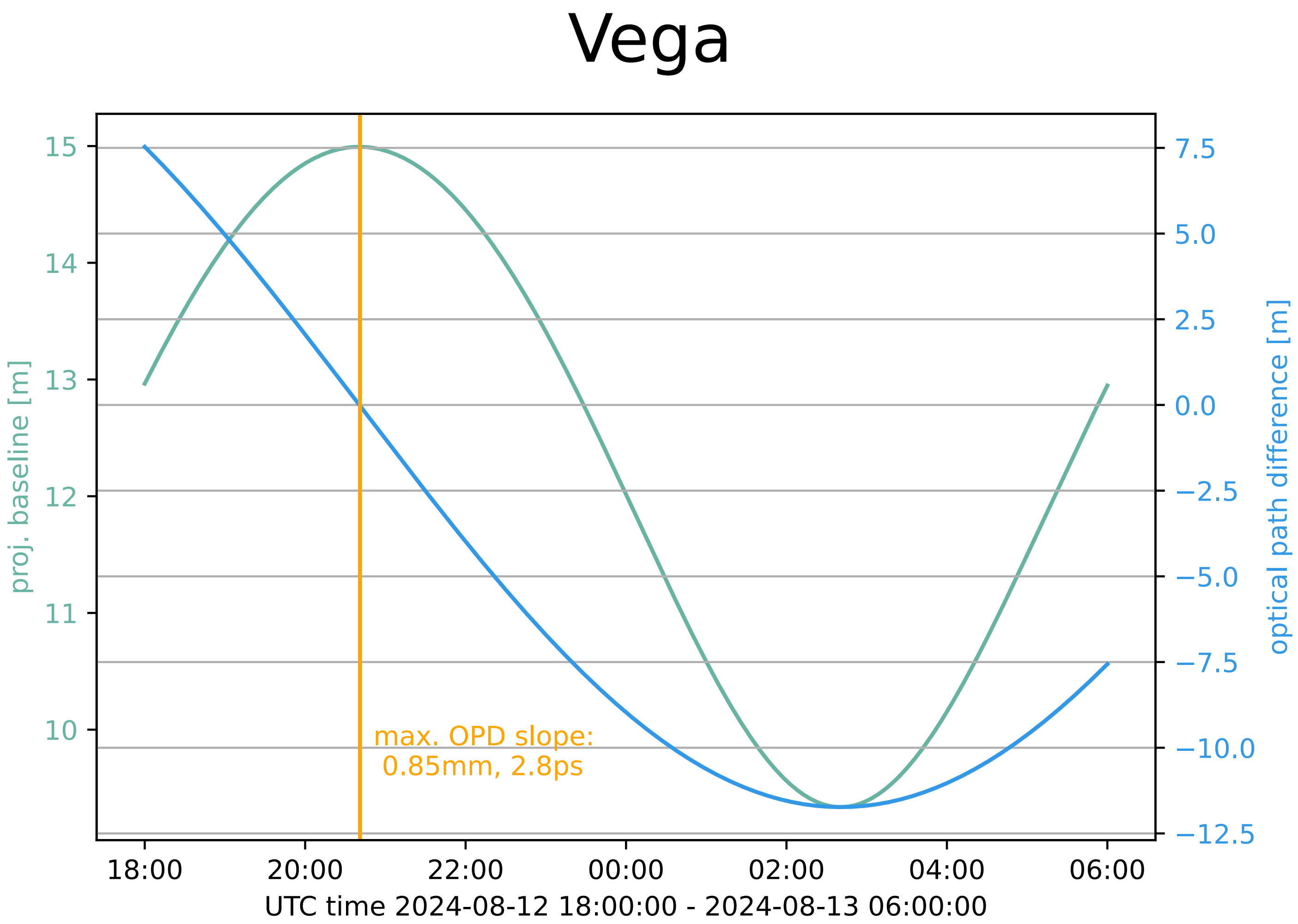
Calculation of baselines

- Absolute baseline of C2PU is 15m
- Baseline changes as star moves over the sky
- Calculate projected baseline for Δt
- Calculate optical path difference (OPD) for Δt
- Shift each histogram accordingly

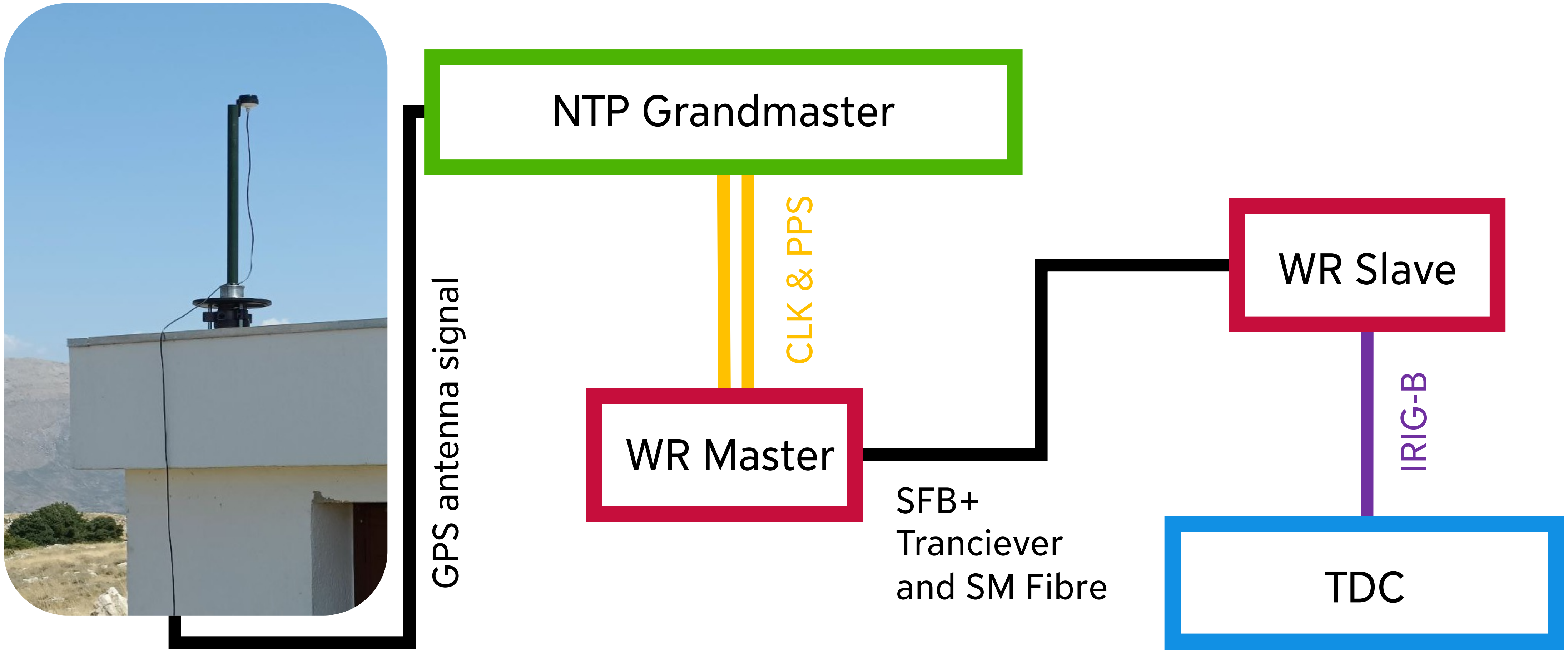


Optical path difference (OPD)

- OPD slope needs to be < timing jitter of system
- Max. OPD slope: 0.85mm, 2.8ps per second
- Need UTC timestamps every second for OPD calculation



Obtaining UTC timestamps



Synchronization Hardware

NTP Grand-master

NTP Grandmaster

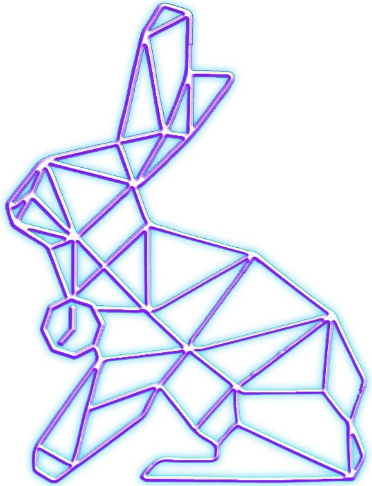
- DTS 4160.Grandmaster from Bürk Mobatime
- 10MHz and PPS output to feed WR
- External time via GPS antenna
- GPS-synchronizable oscillator
- Oven Controlled Crystal Oscillator: 5 ps/s
- Provides UTC timestamps

Synchronization Hardware

White Rabbit LEN

NTP Grand-master

White Rabbit (WR)



- WR LEN Standalone kit
- Synchronization over daisy chain configurations
- Distribute accurate timing
- Sub-nanosecond time accuracy
- Distance range: Over 80km fiber
- Dual optical fiber
  Ethernet 1G interfaces
- Synchronize IRIG-B device

Synchronization Hardware

White Rabbit LEN

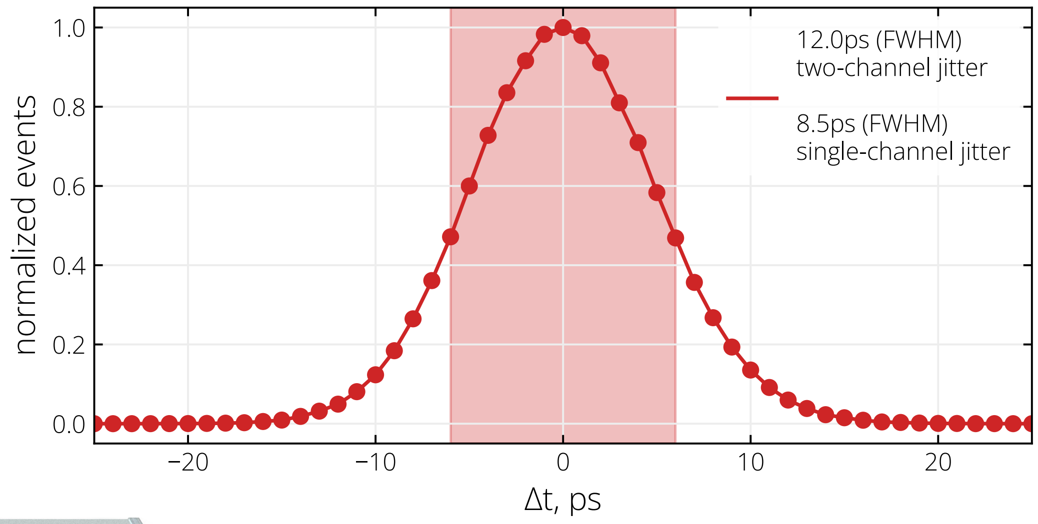
NTP Grand-master

LINTag TDC

LINTag from Photonscore

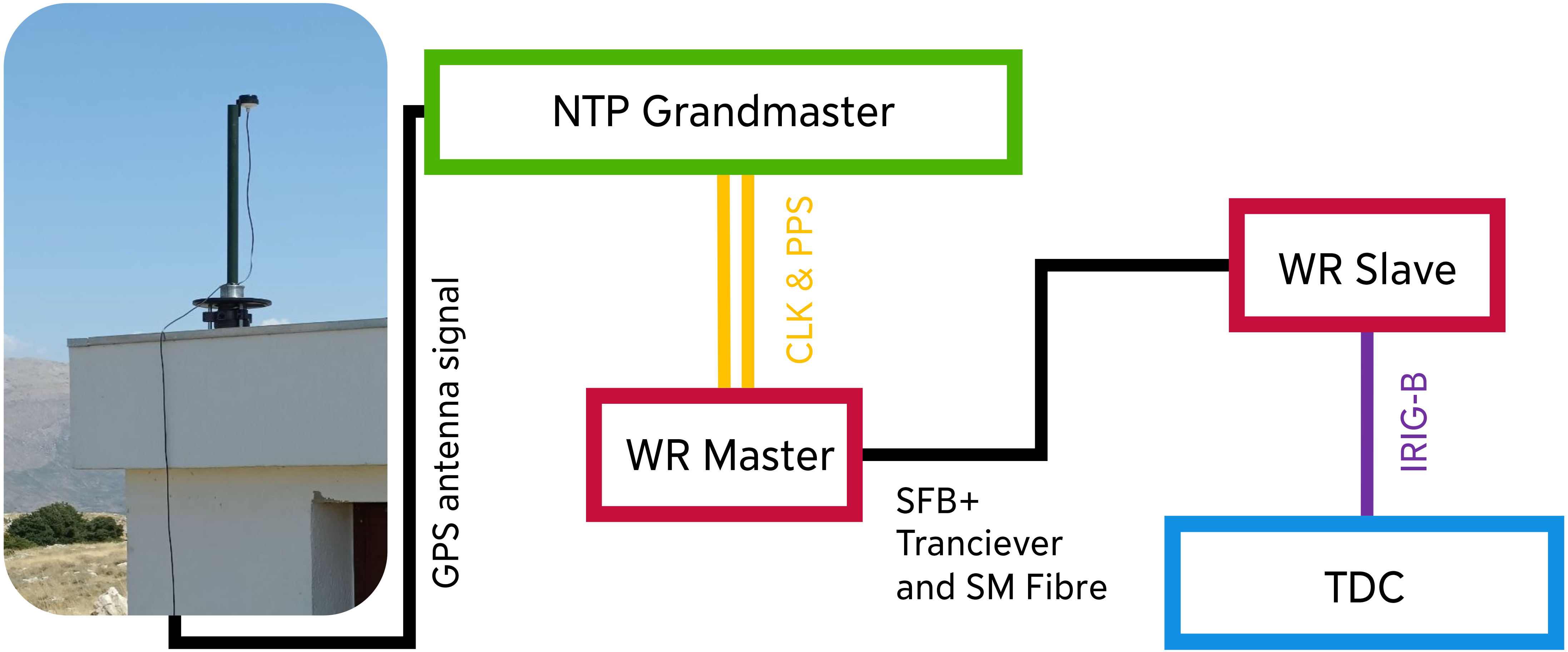
- time-tagger system for ultra-fast data acquisition
- Temporal accuracy of 8.5ps (FWHM) / 3.6ps (RMS)
- 10G Ethernet SFB+ connection
- full-stack TCP/IP interface
- Transfer up to 400 MEvents/s
- Multi-Start Multi-Stop correlation

Timing jitter



Photonscore.
PHOTON COUNTING MADE EASY

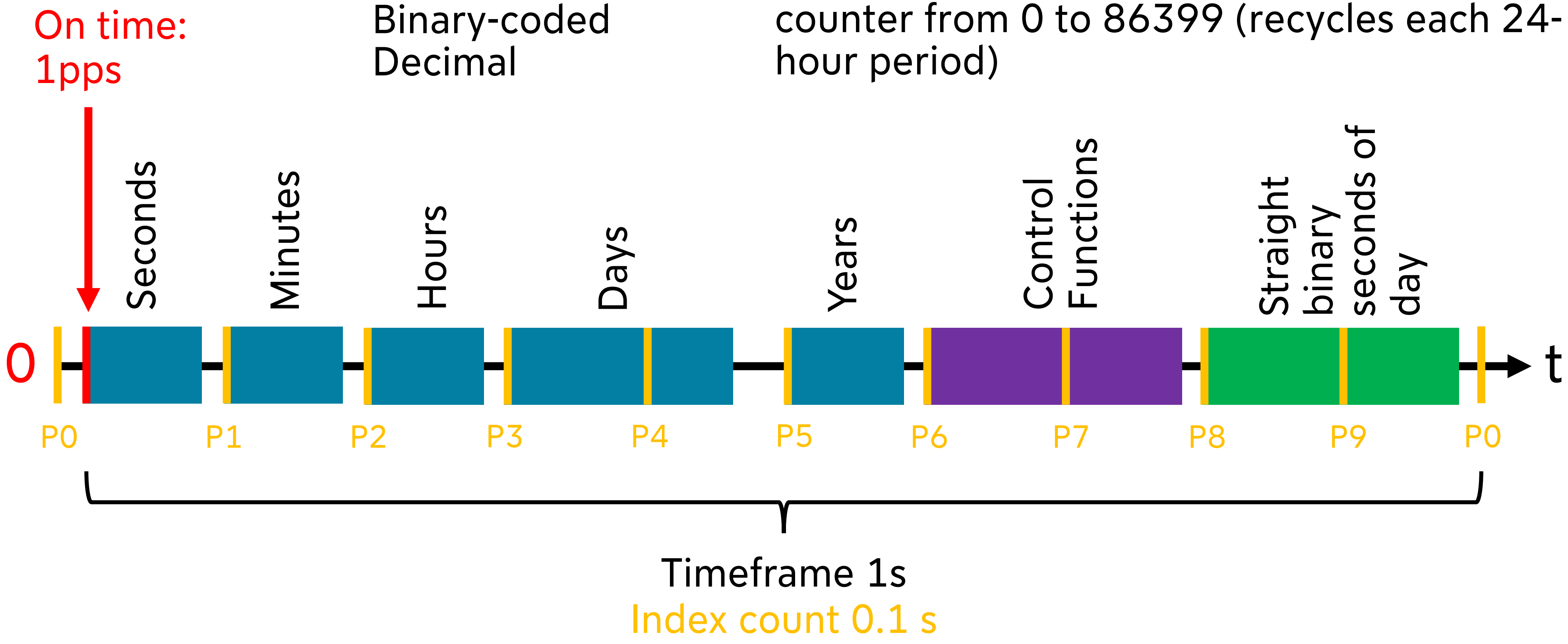
Obtaining UTC timestamps



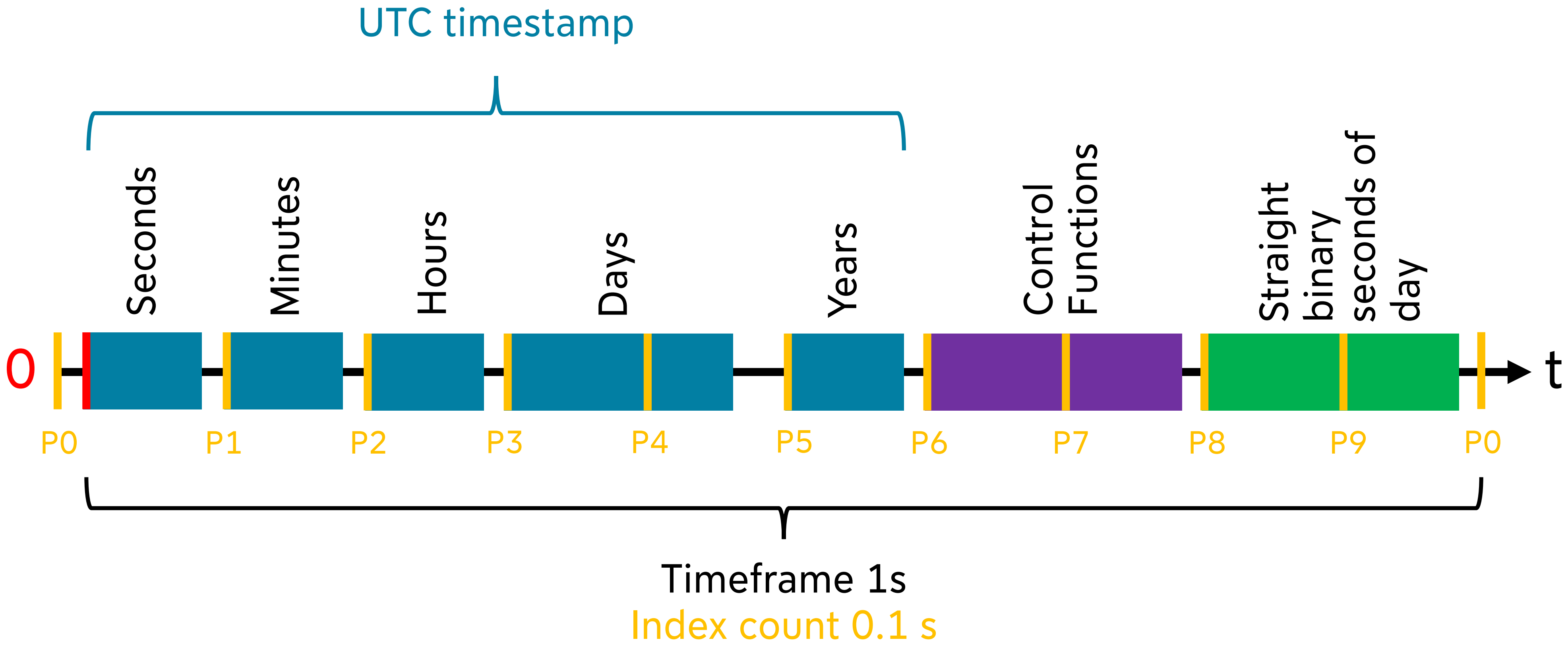
IRIG-B timecode

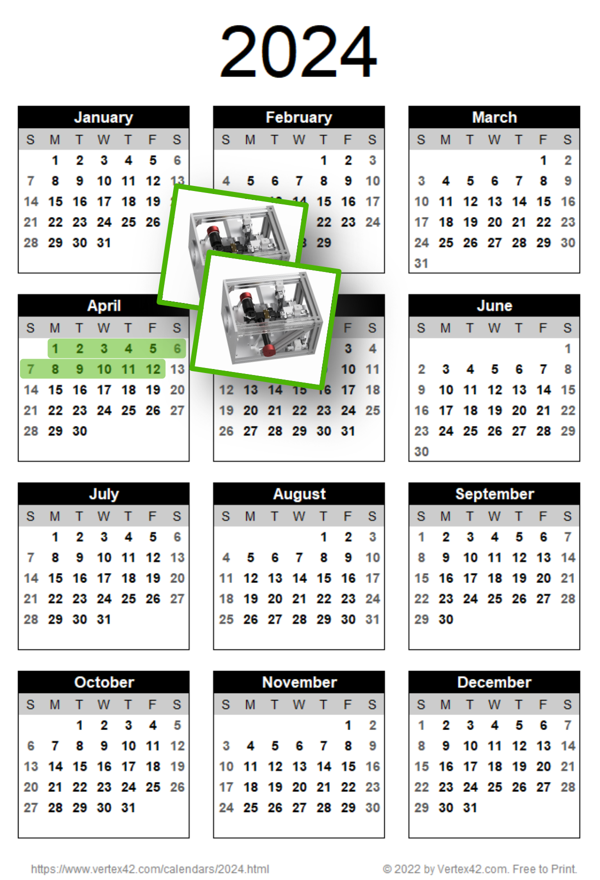
- 100MHz bit rate
- Encoding type: Binary-coded Decimal

- Years as number 00-99 (00=2000)
- Straight binary seconds: 17 bit binary counter from 0 to 86399 (recycles each 24-hour period)



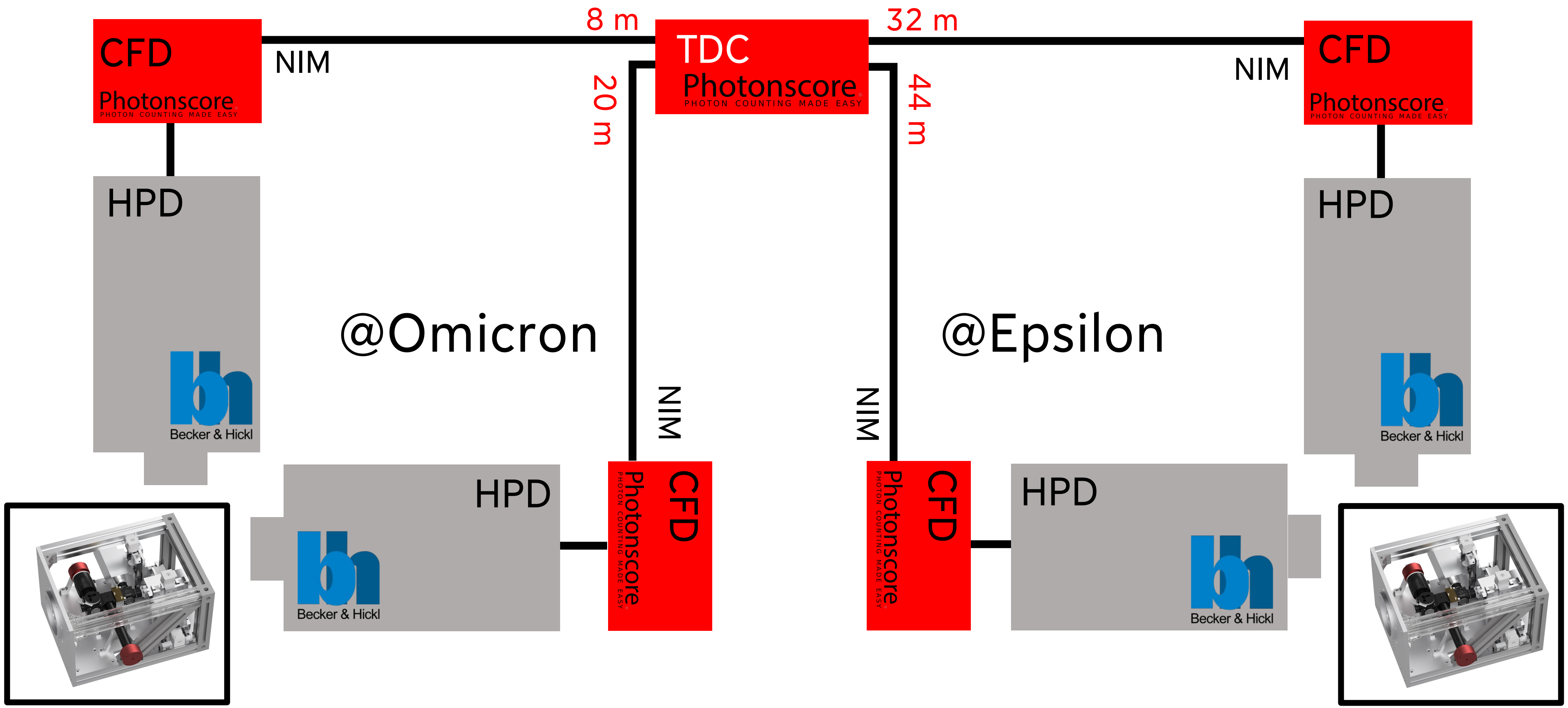
IRIG-B timecode





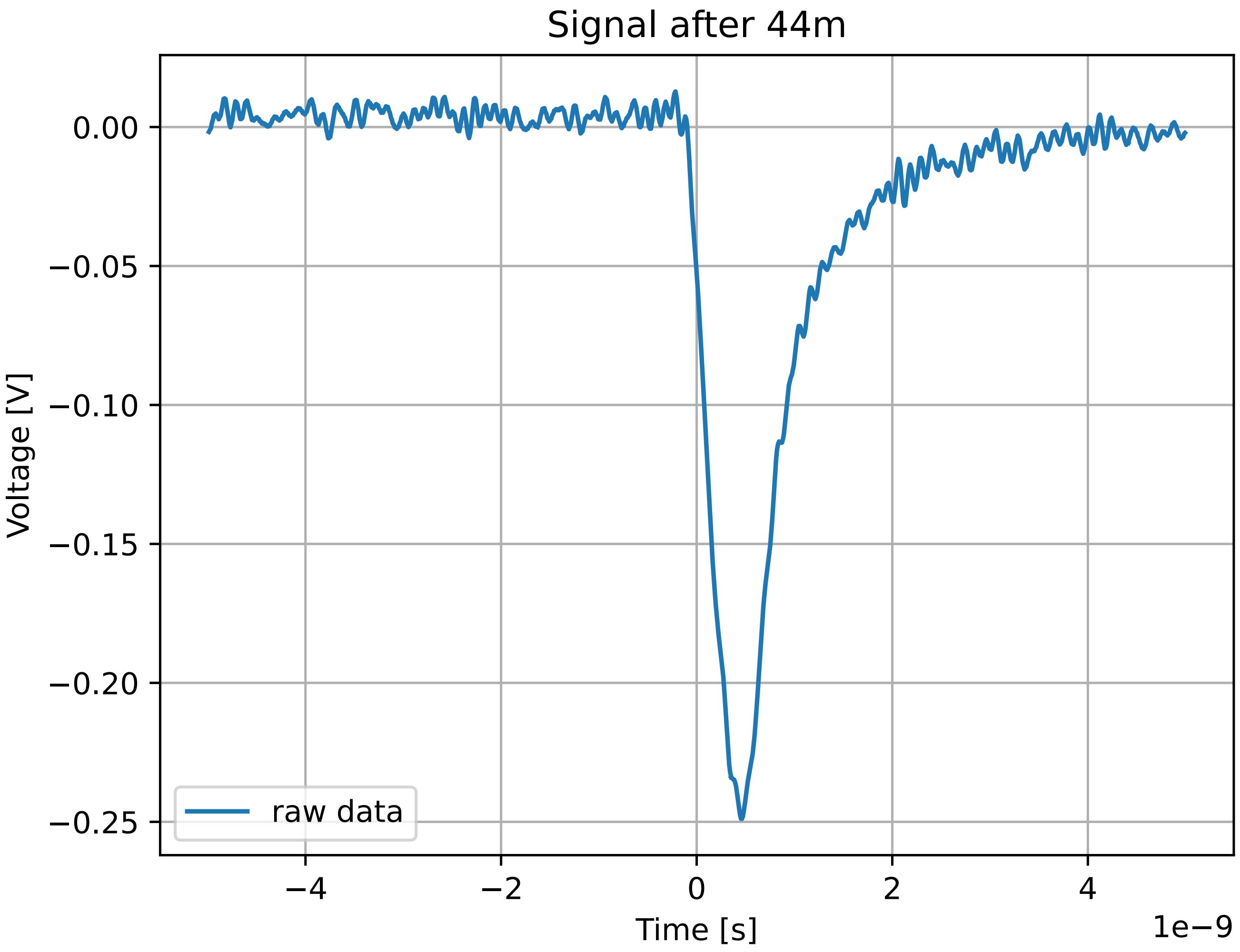
Spatial Correlations using HPDs

Measurement Configuration



Cabel lengths

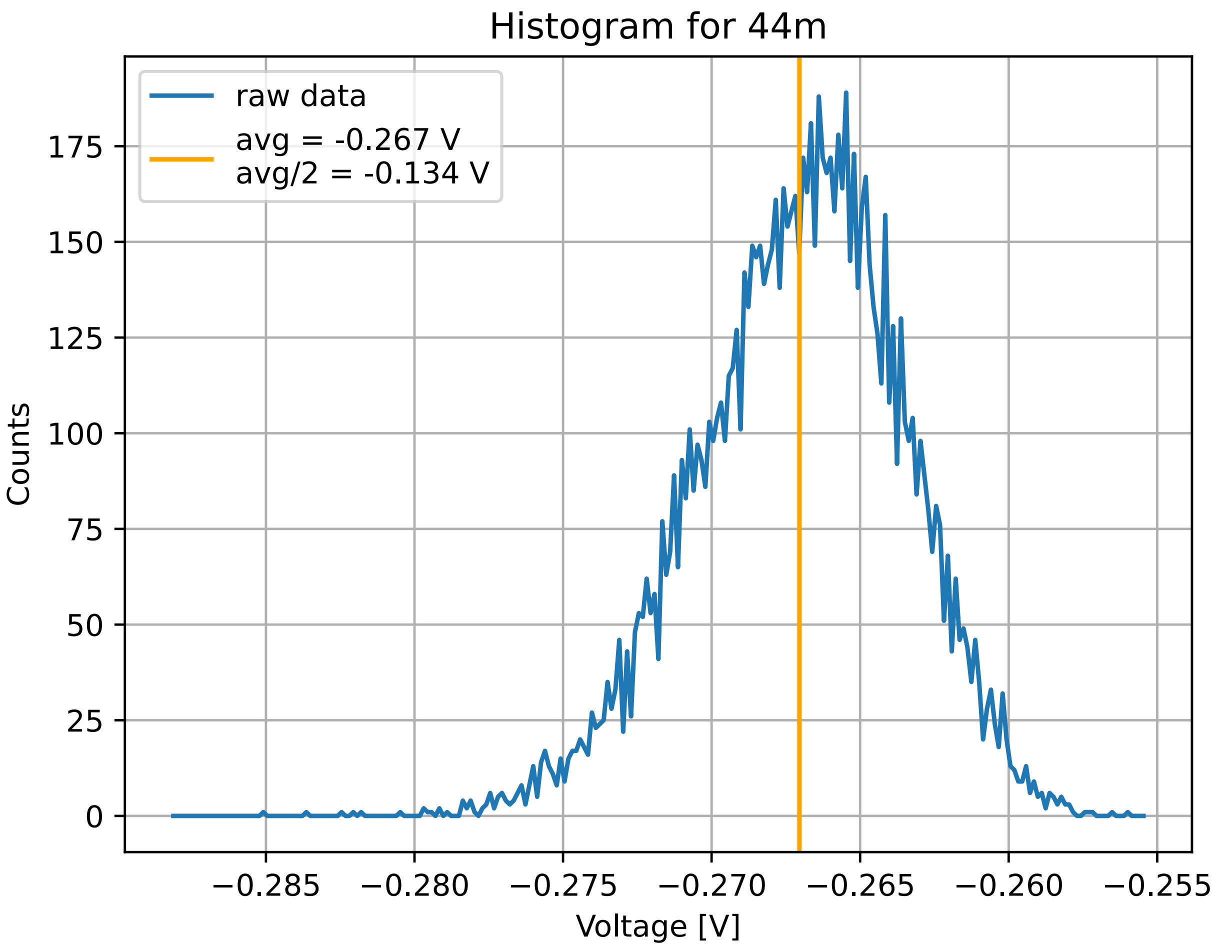
- Cable length difference: 12m to be far away from cross talk
- Hubert + Suhner 18GHz cable, semi-rigid
- NIM signal from CFD gets attenuated in cable



Cabel lengths

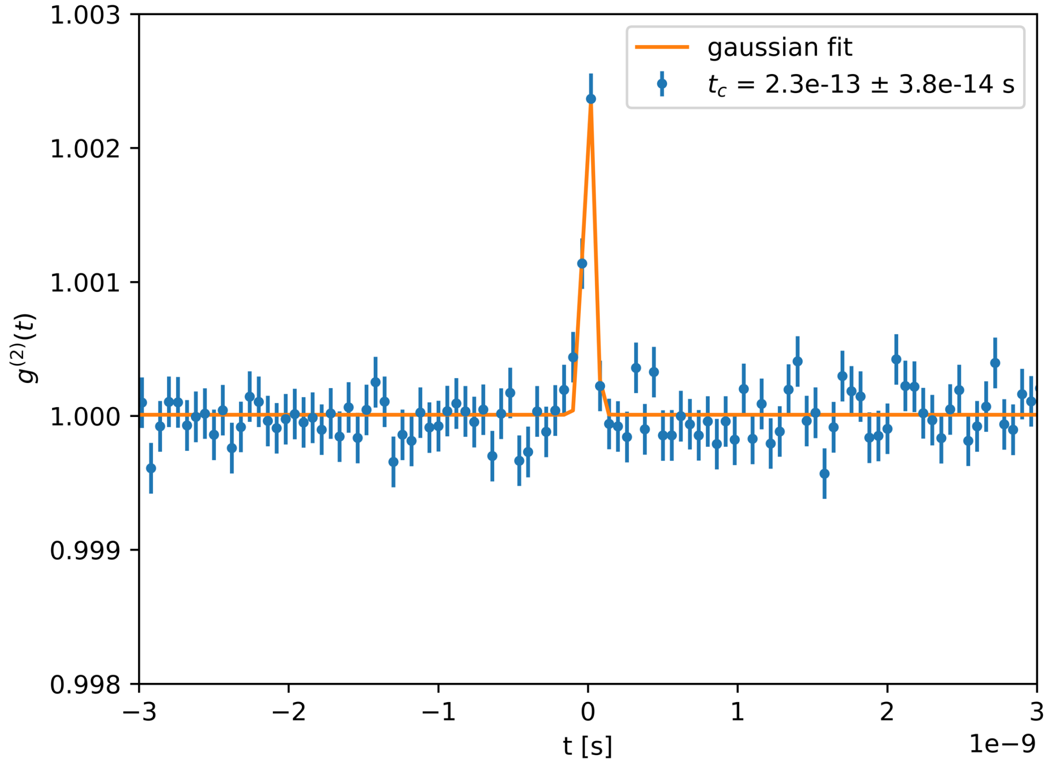
- Cable length difference: 12m to be far away from cross talk
- NIM signal from CFD gets attenuated in cable
- Adjust trigger level in TDC

Cable length [m]	Trigger level [V]
8	-0.260
20	-0.211
32	-0.175
44	-0.134

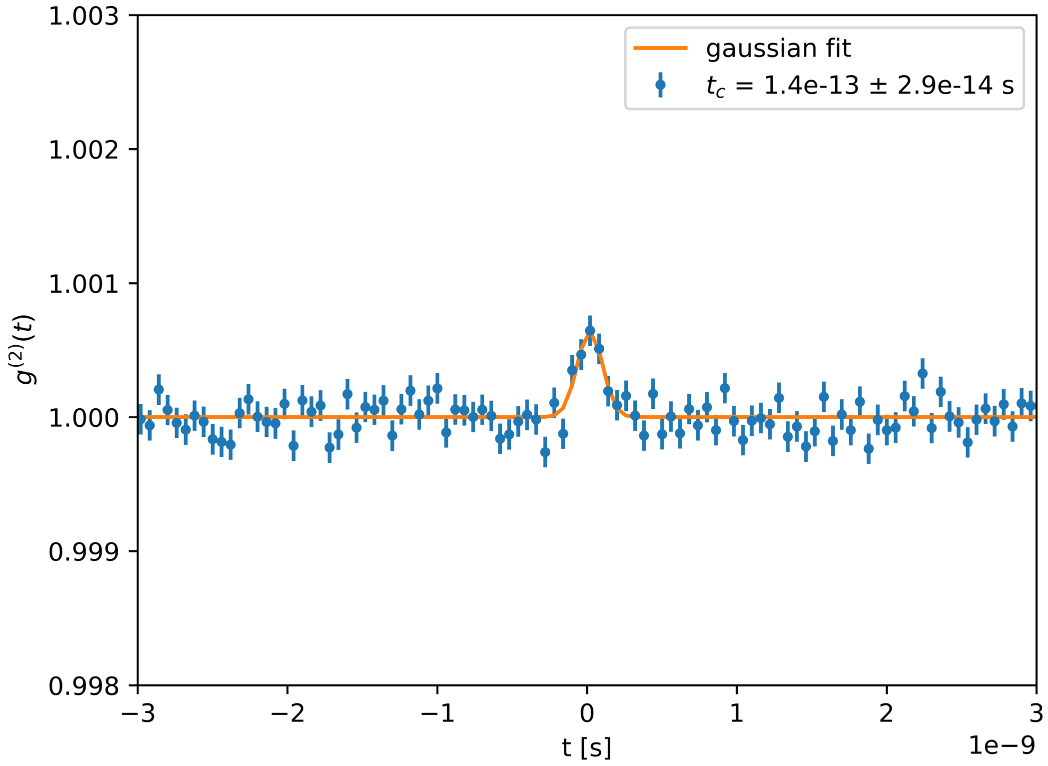


Results for Vega using HPDs

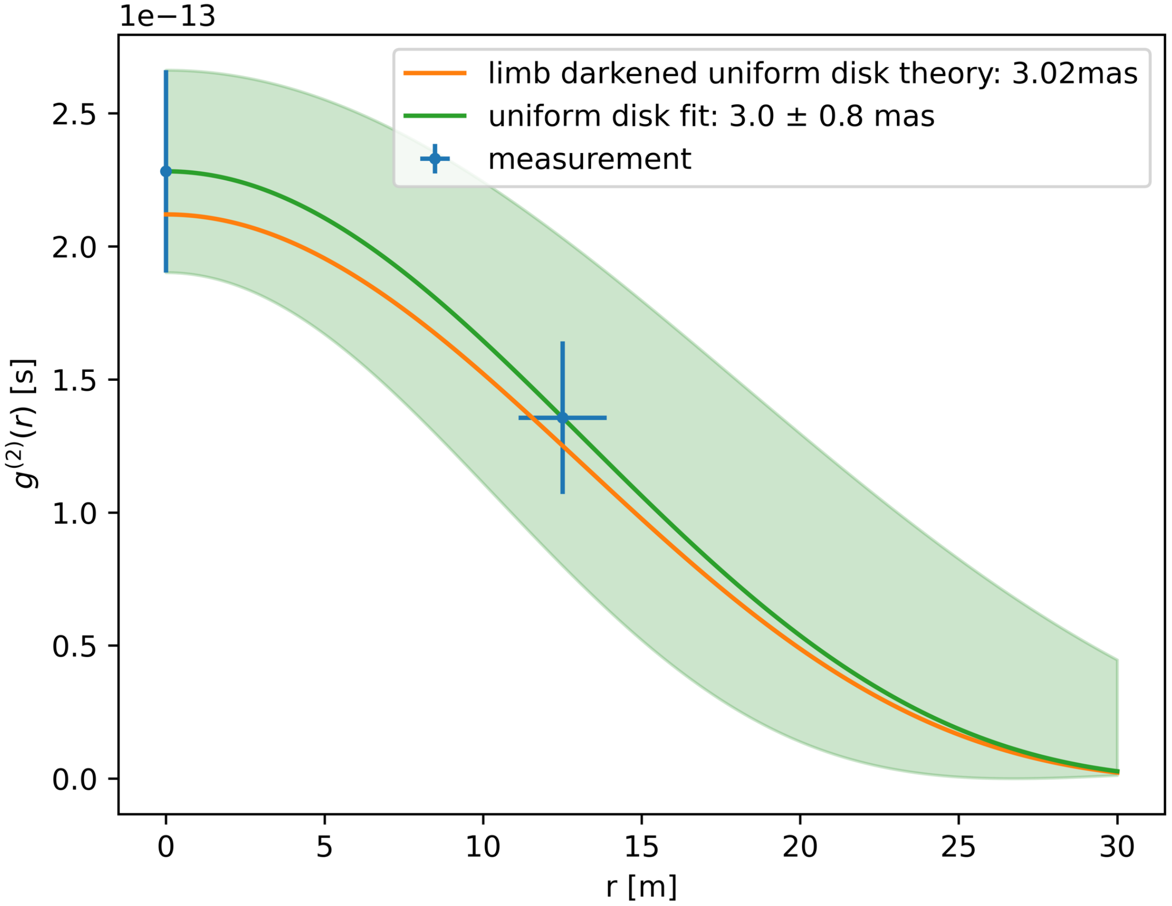
Bunching



Cross-Correlation



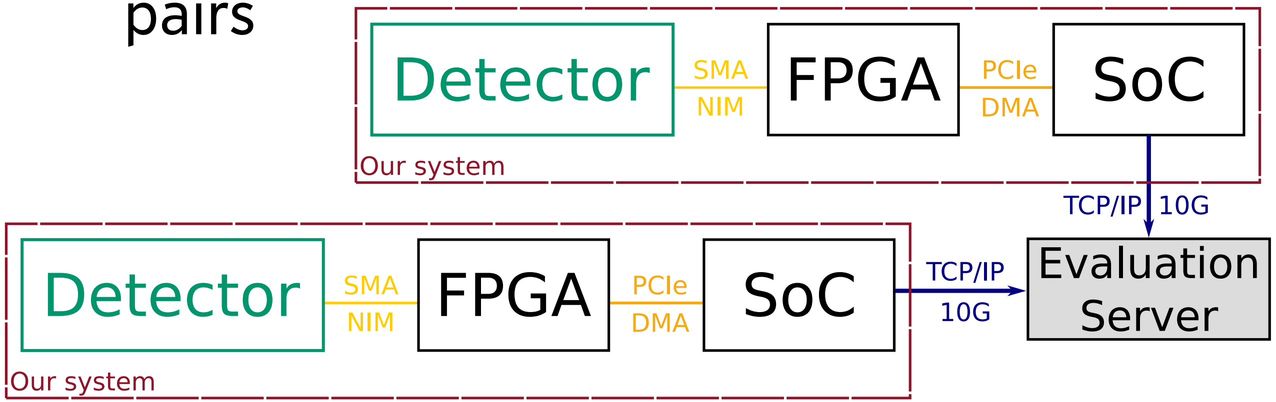
Visibility curve for Vega



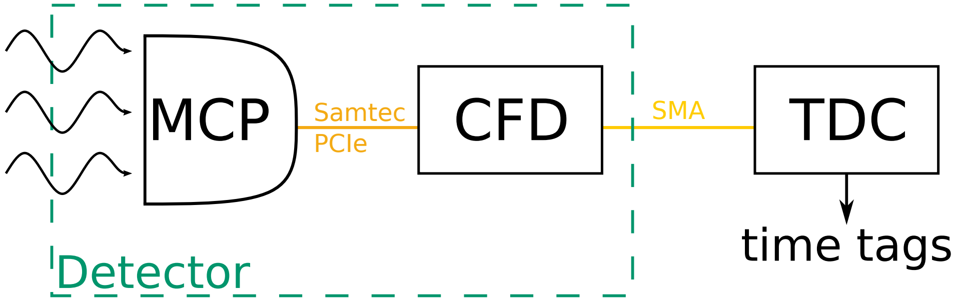
High Throughput System (HTS)

High Throughput System (HTS)

- Detector = LINPix and TDC = LINTag
- Timetags of FPGA will be sorted and compressed by SoC
- reliable, ordered and error-checked data delivery to server
- Evaluation server correlates all channel pairs



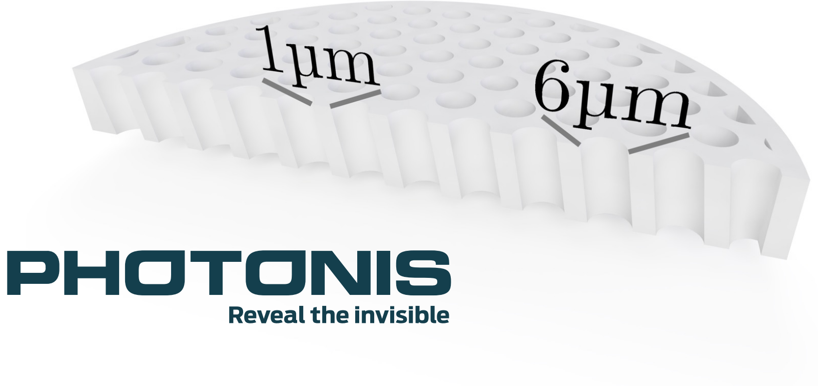
LINPix from Photonscore

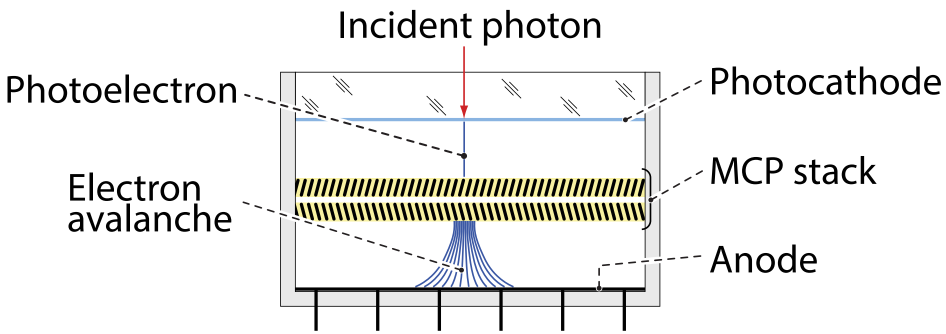


- Integrated CFD
- NIM output
  → long cables
- Count rates >100MHz
- Ø8mm active area

LINPix from Photonscore

Ceramic Vacuum Assembly: Photocathode + Multichannel Plates



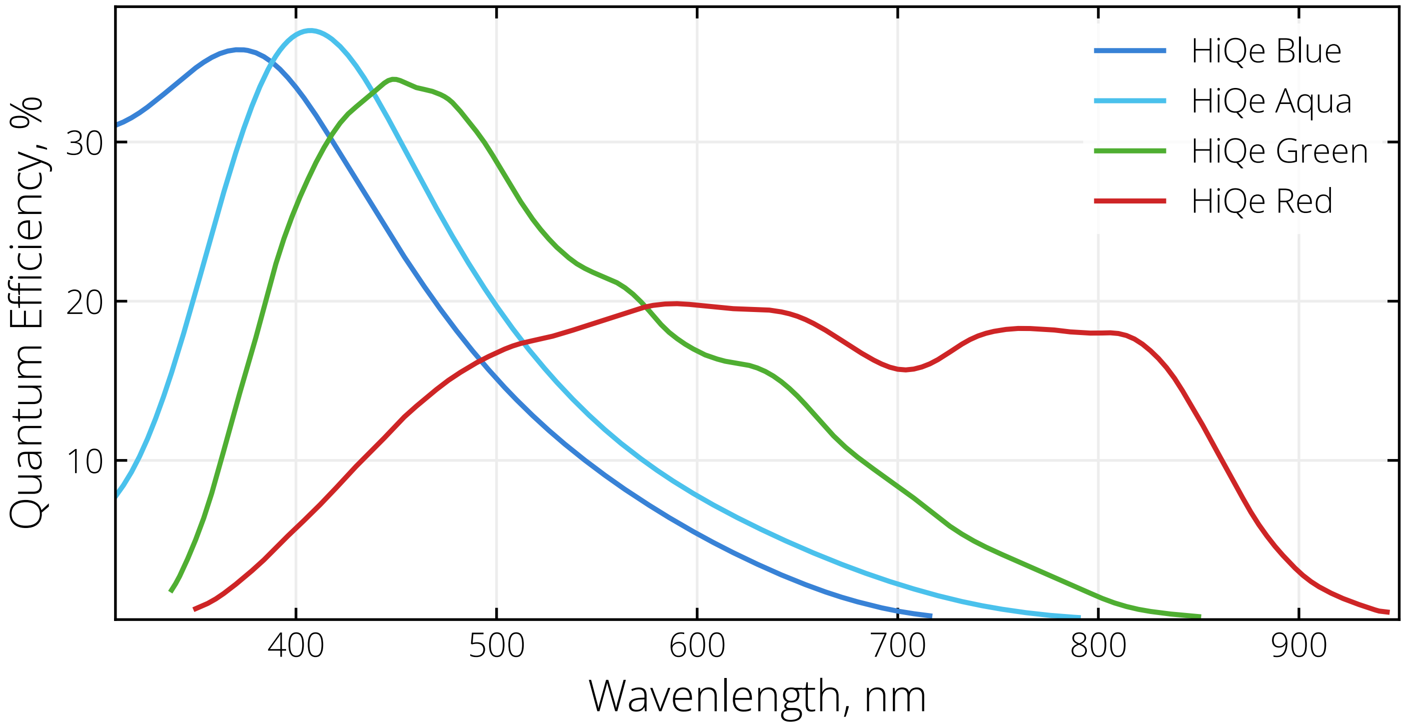


- Channel width = 6μm
- Channel distance = 1μm
- Channel tilt = 5 - 10°
- Chevron stack → gain > 10^6

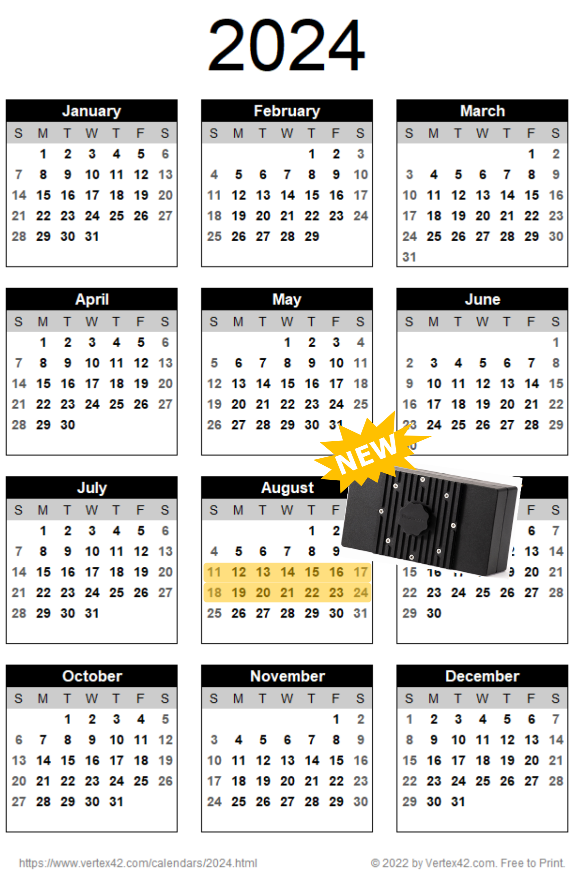
Photonscore.
PHOTON COUNTING MADE EASY

Possible Photocathodes for LINPix

Quantum efficiency

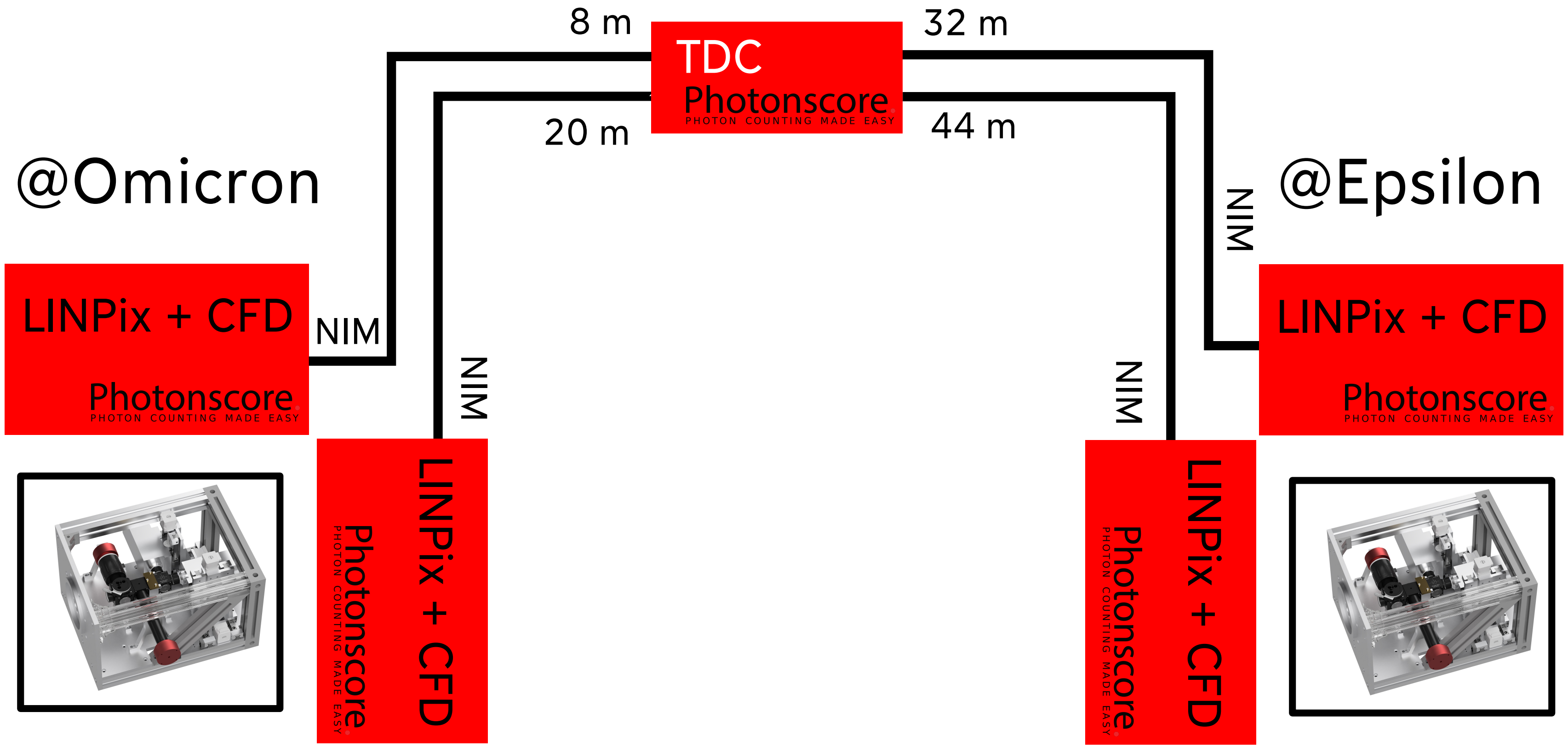


Used 3 HiQe Aqua and 1 HiQe Blue @405nm



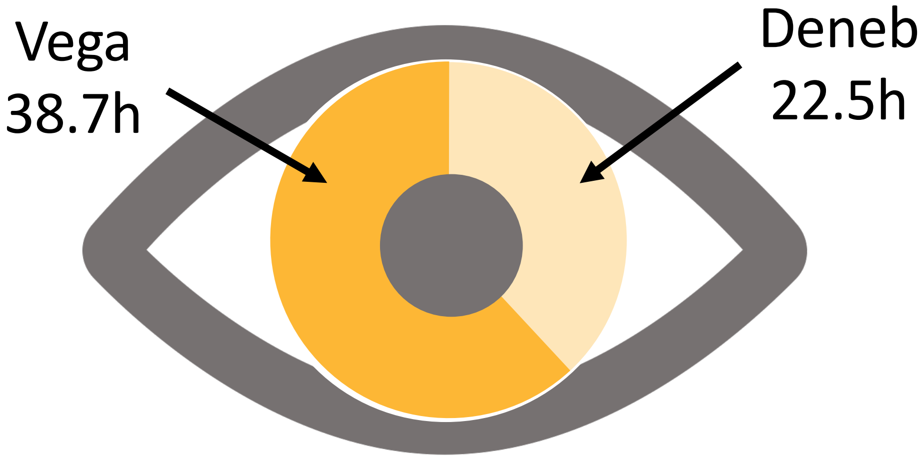
Spatial Correlations using HTS

Measurement Configuration

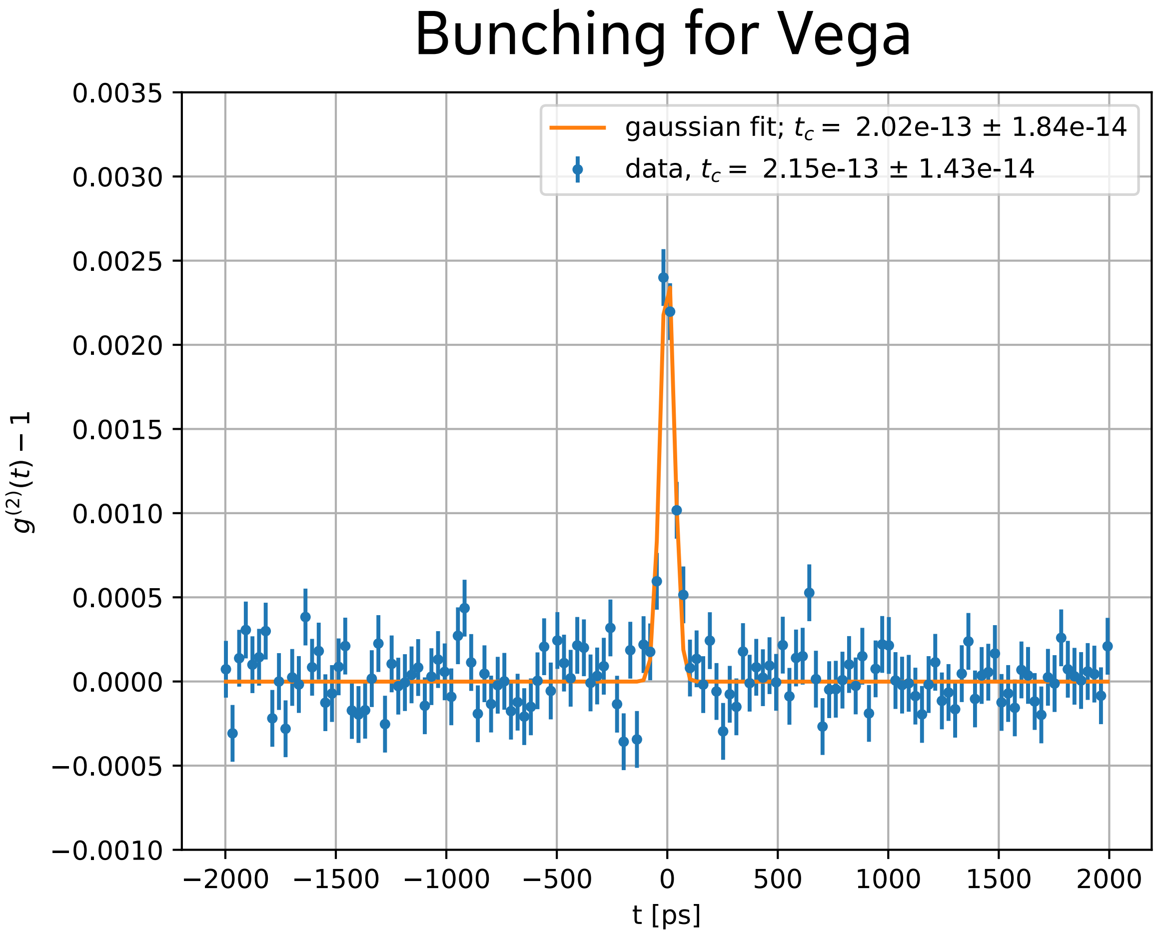


Temporal Correaltions using HTS

Observation Time

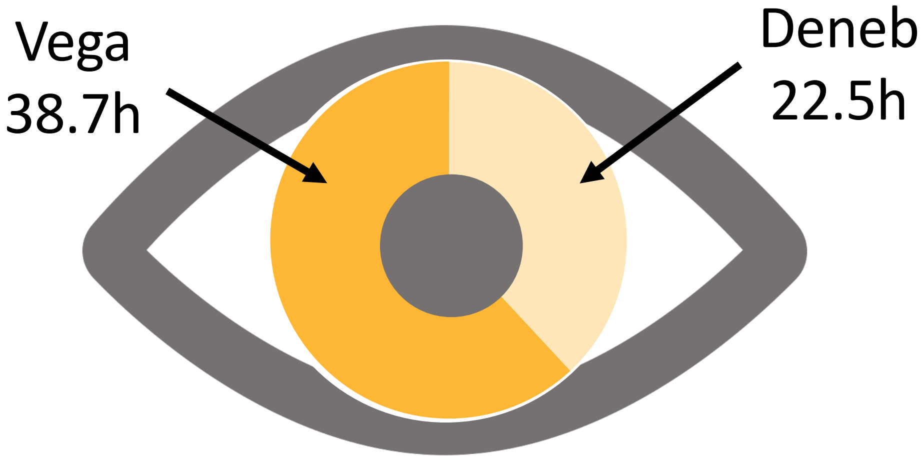


App. Magnitude

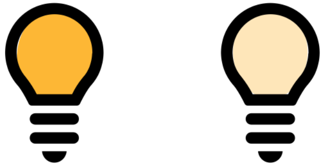


Spatial Correaltions using HTS

Observation Time



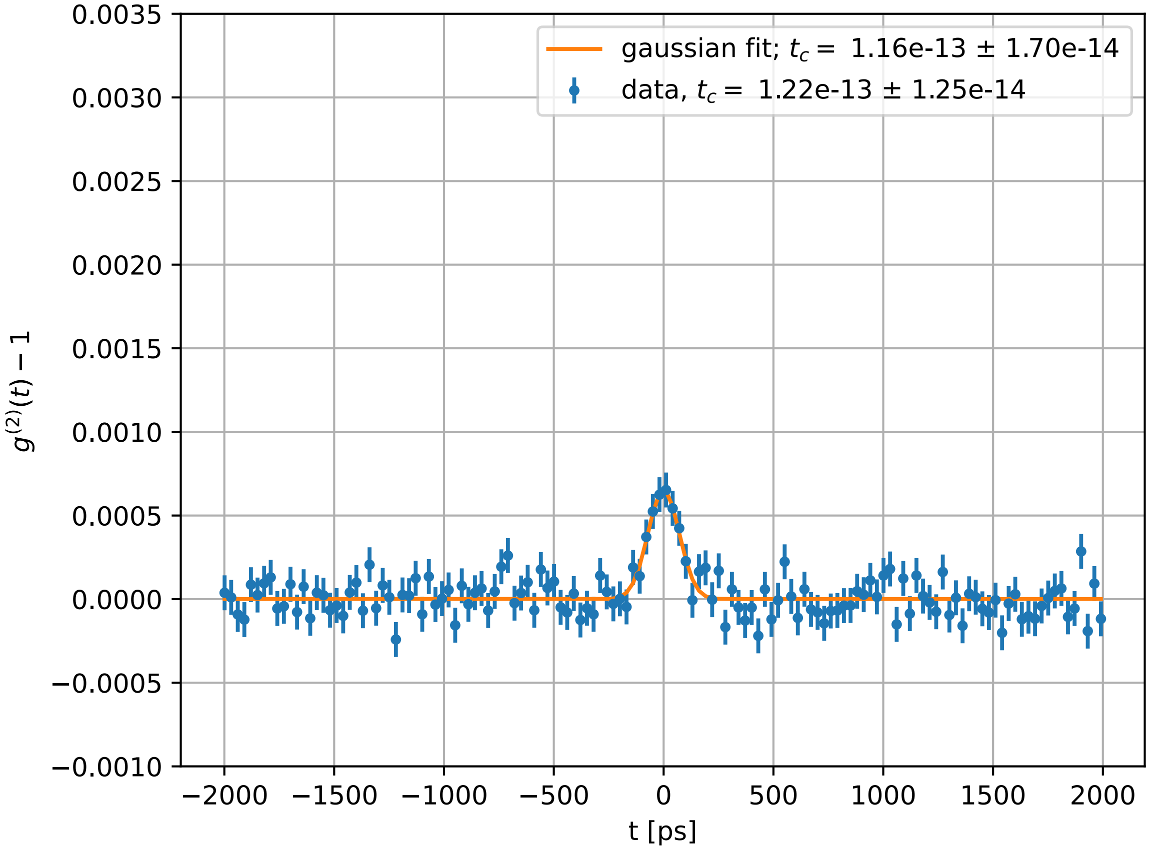
App. Magnitude



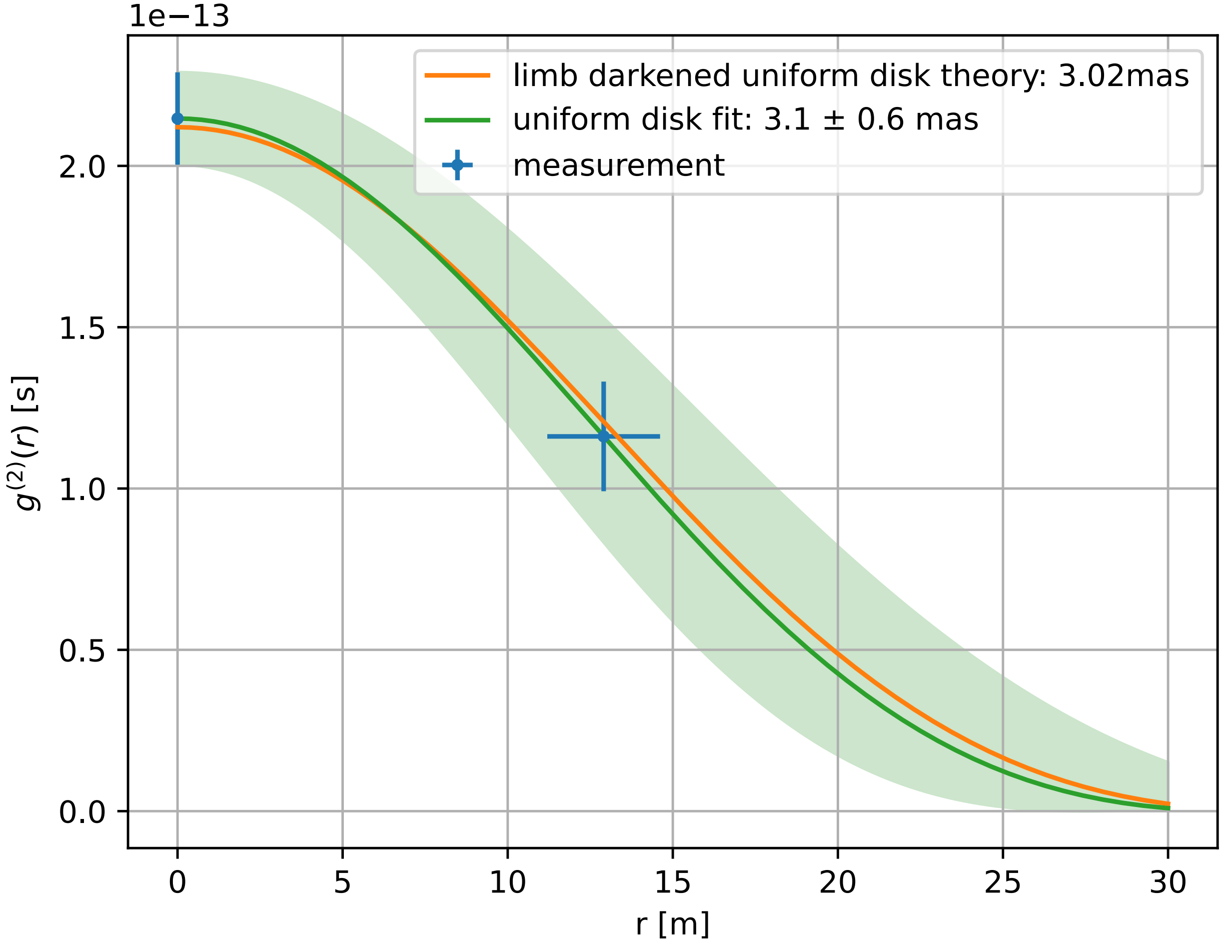
Vega 0.026

Deneb 1.25

Result for Vega



Visibility curve for Vega



Summary & Outlook

Summary and Outlook

Summary

- Verified stability of setup
- Measured Bunching and spatial correlations using HPDs
- Successfully tested LINPix and LINTag

To Do:
1) Check filter position
2) Higher count rates?
3) Bursts?
4) Km baselines?

Outlook

1) Measure backreflection
2) Try 100MHz bunching
3) Check burst capability of LINPix
4) Try WR with long fibers and test synchroniz-ability of multiple TDCs


Thank you
for your attention

Image References

- HPD: taken from Becker&Hickl manual
- CFD1: https://upload.wikimedia.org/wikipedia/commons/8/8f/Constant_fraction_1.svg
- CFD2: http://lmu.web.psi.ch/docu/manuals/bulk_manuals/software/TDC/CFD_signals.png
- quTAG: taken from quTools website
- WR: https://www.eenewseurope.com/en/white-rabbit-deal-boots-timing-synchronisation/
- WR Len: taken from Safran website
- NTP Grandmaster: taken from Bürk Mobatime website
- LINTag plot and image: taken from Photonscore manual and website
- Vacuum assembly: copyright Photonis
- MCP: copyright Stefan Richter
- MCP schematic: copyright Yury Prokazov
- LINPix: taken from Photonscore website
- Quantum efficiency: taken from LINPix Photonscore datasheet