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ASTRI

Assembly, Integration, and Verification of the laboratory prototype of the ASTRI Stellar Intensity Interferometry Instrument (SI^3)

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for the ASTRI-SI3 team and the ASTRI Project

Stellar Intensity Interferometry Workshop 2024, Porquerolles (France)
13 September 2024

Outline

Mini-Array

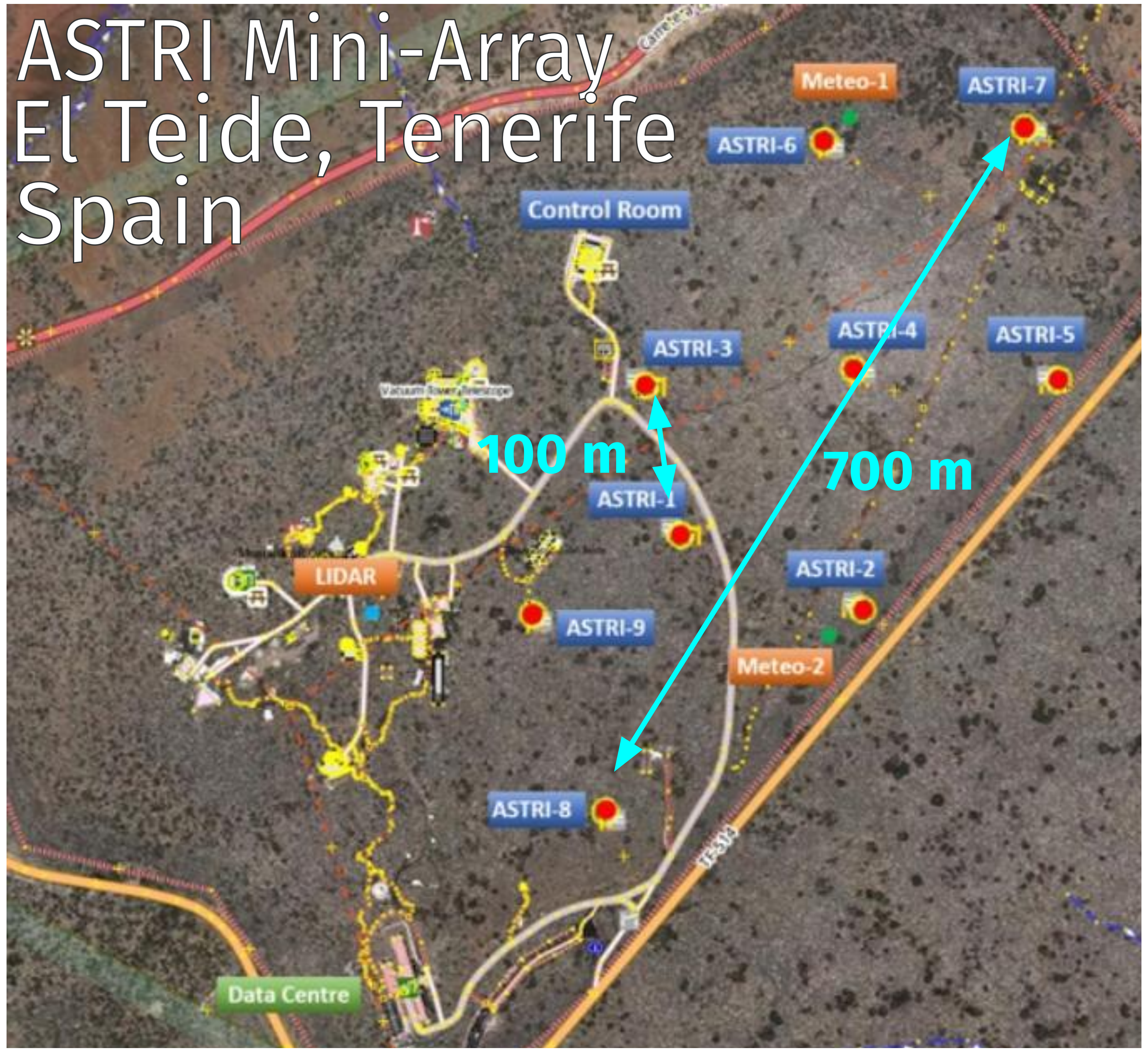
- Short introduction to ASTRI SII Instrument (SI3)
  - SI3 Version 2
  - Detectors and Acquisition System
  - Test on Detectors and Acquisition System

- Assembly, Integration and Verification (AIV) of the Commercial Detector and Acquisition System
  - ASTRI/AQUEYE Laboratory
  - ASTRI Mini-Array time synchronization system
  - Time reconstruction algorithm
  - TDC internal jitter
  - Laboratory setup for correlation measurements
  - Linearity curve and Jitter
  - Correlation Measurements

- Conclusions

ASTRI SII Instrument (SI^3)

The **ASTRI Mini-Array** is an International collaboration, led by the Italian National Institute for Astrophysics (INAF), that is constructing and operating an array of nine Imaging Atmospheric Cherenkov Telescopes to study gamma-ray sources at very high energy (TeV) and **perform optical stellar intensity interferometry observations**

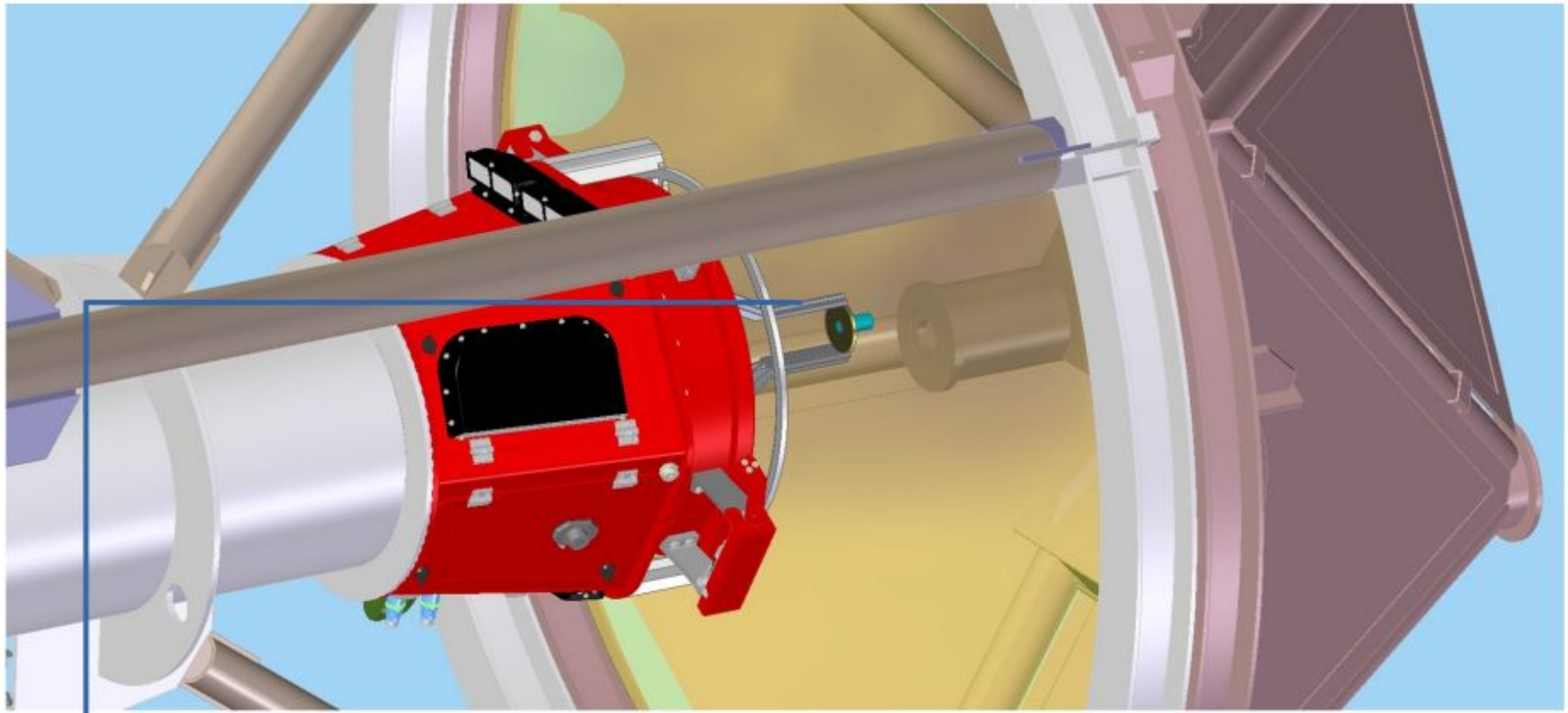


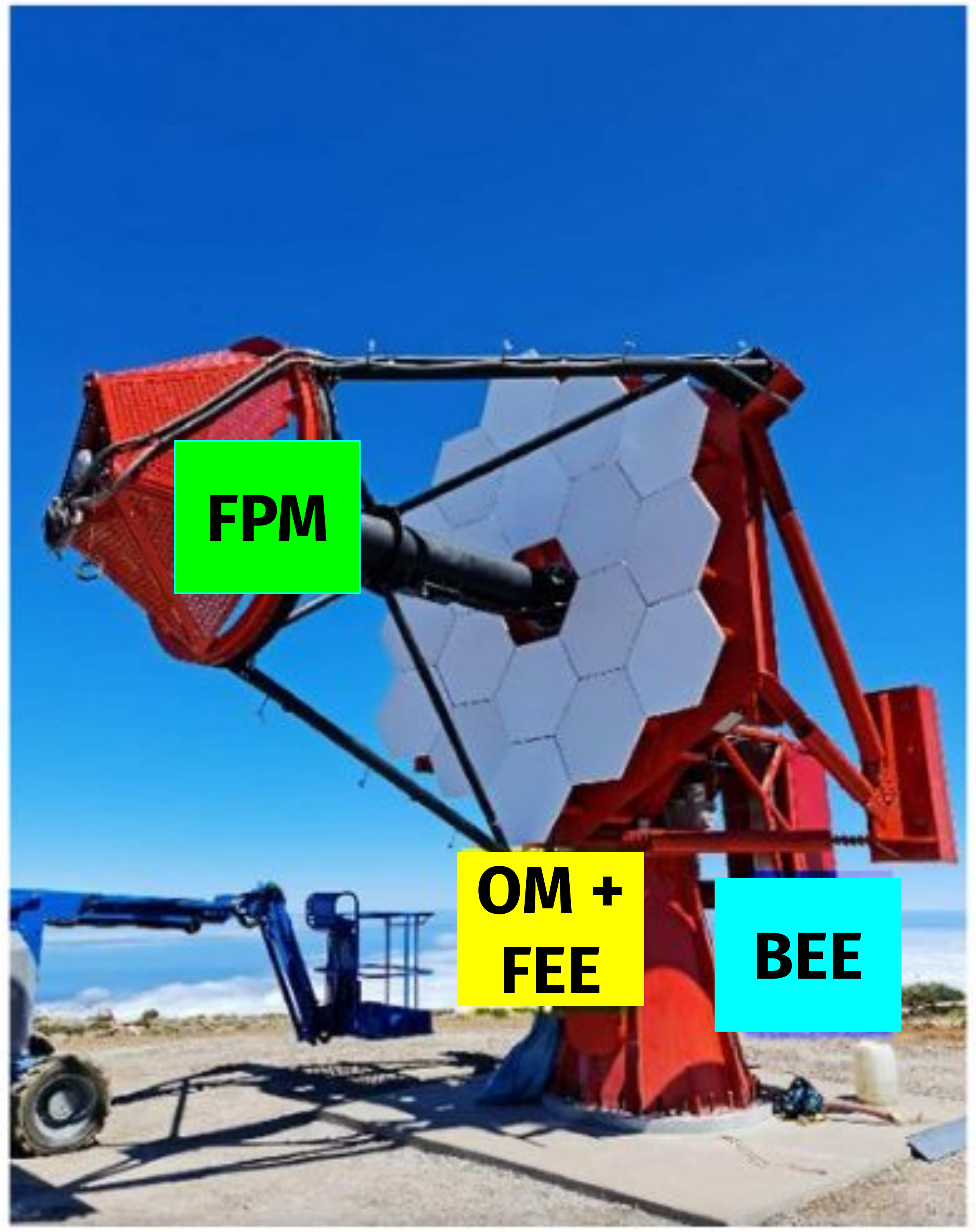
Stellar Intensity Interferometry with ASTRI

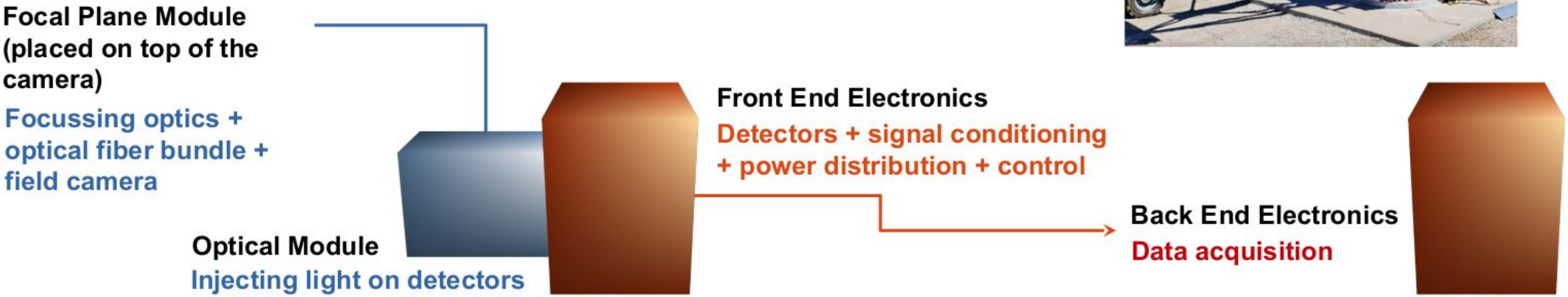
The ASTRI Mini-array provides a suitable infrastructure for performing SII measurements at sub-milliarcesec level

Ultimate goal: using the **long (up to ~700 m) multiple baselines (36)** of all 9 ASTRI Mini-Array telescopes to do image reconstruction with resolution of **~100 microarcseconds**

SI^3 Version 2
Instrument Design



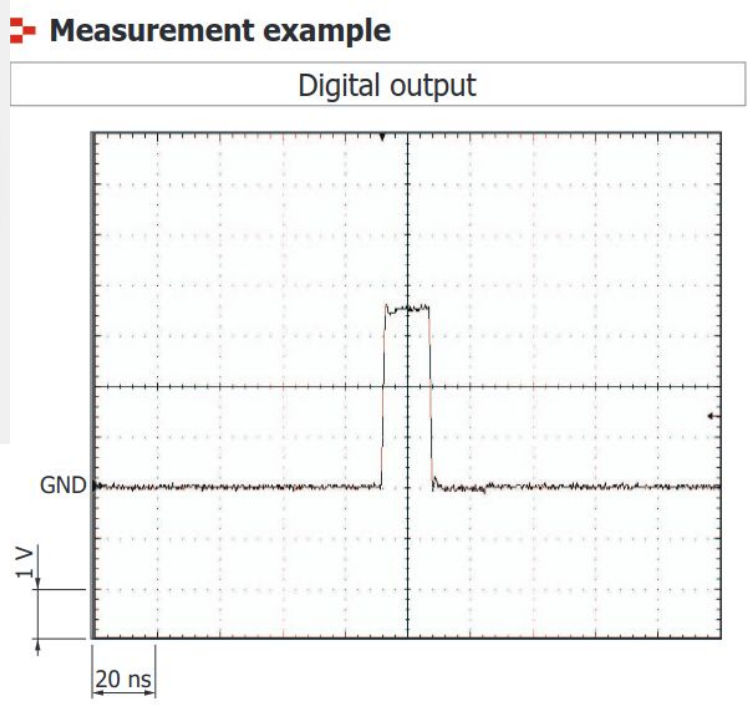




Zampieri et al. (2024)

SI³ Version 2
Detectors and Acquisition System

Digital signal from FEE



x4

Time-to-Digital Converter (TDC)
Time Tagger Ultra
Swabian Instruments

Workstation
Super Tower 732D3-903B
Supermicro

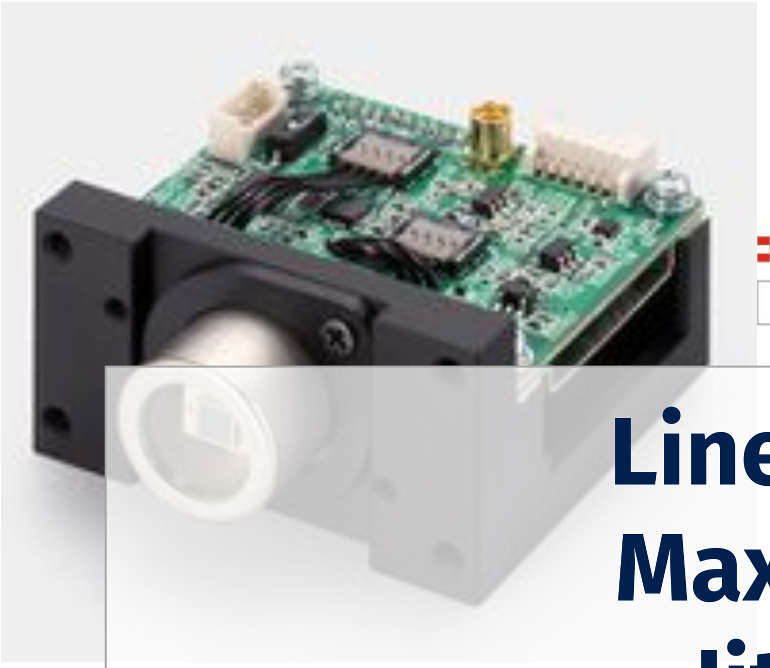
Time Distribution Unit (TDU)
White Rabbit system

PPS signal + Clock reference signal

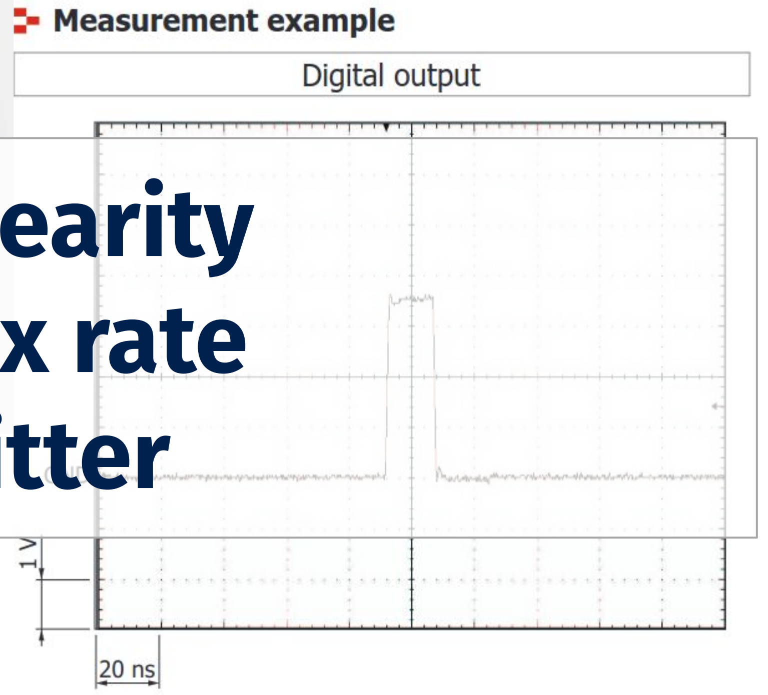
To Array Data Acquisition System
1.12 Gb/s max rate

SI^3 Version 2
Test on Detectors and Acquisition System

ASTRI Mini-Array



Digital signal from FEE



Linearity
Max rate
Jitter

x4

Time-to-Digital Converter (TDC)
Time Tagger Ultra
Swabian Instruments

Max rate
Jitter
Channels cross-talk
Internal clock stability

Workstation
Super Tower 732D3-903B
Supermicro

Time Distribution Unit (TDU)
White Rabbit system

UTC synchronization
Time-reconstruction algorithm

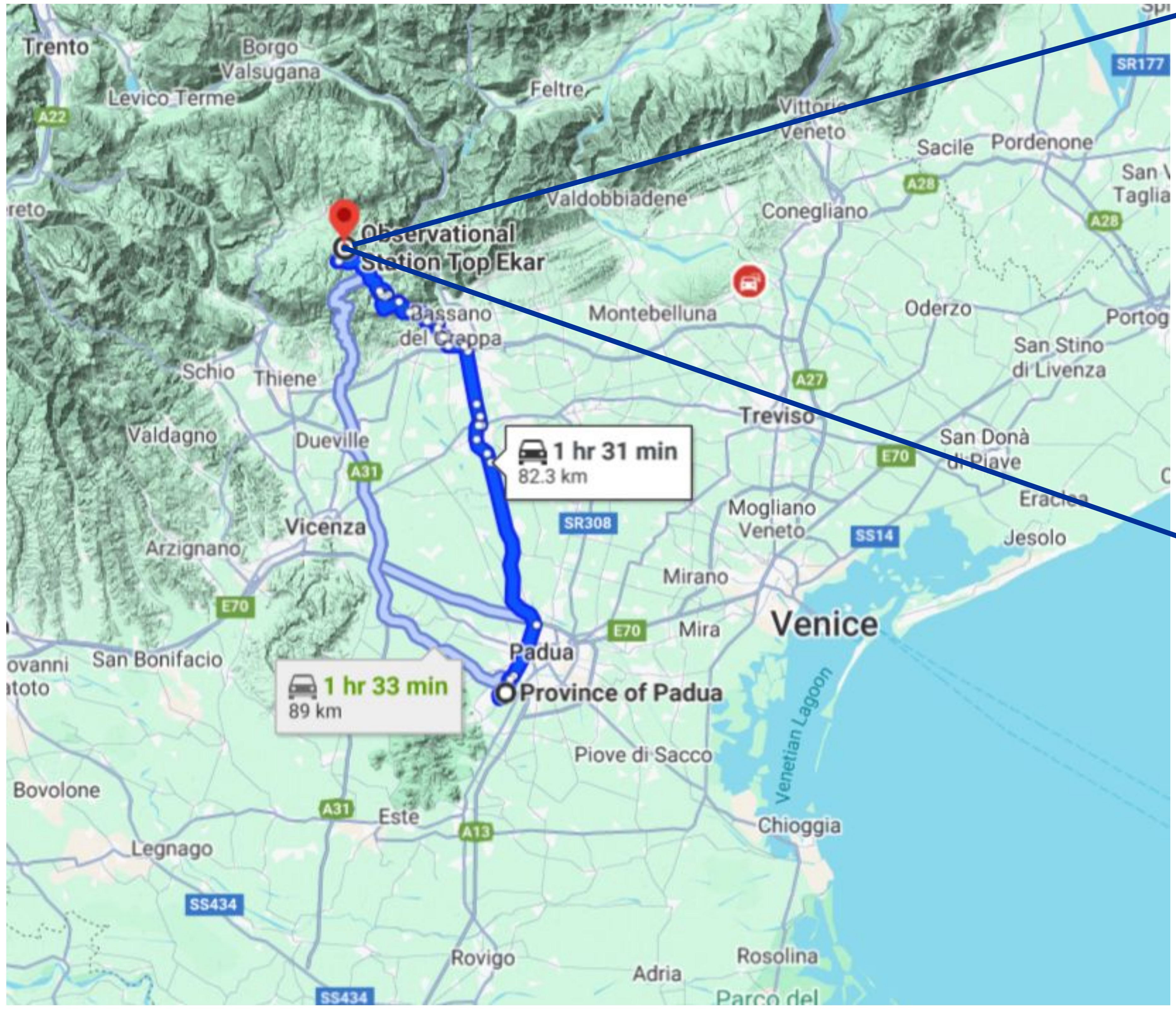
PPS signal + Clock reference signal

To Array Data Acquisition System
1.12 Gb/s max rate

Overall performance of the electronics of SI^3

AIV
ASTRI/AQUEYE Laboratory

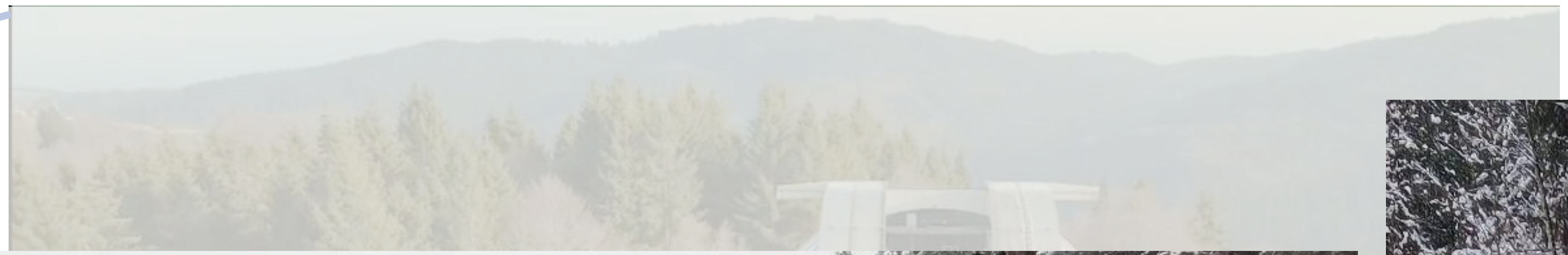
Mini-Array

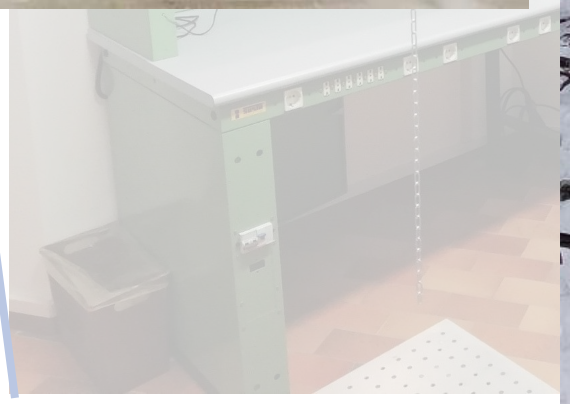


Laboratory located at Cima Ekar (Asiago) in the Copernico telescope building.

Intensive testing campaign started in 2023. From January 2024 almost every Thursday was dedicated to test

AIV
ASTRI/AQUEYE Laboratory

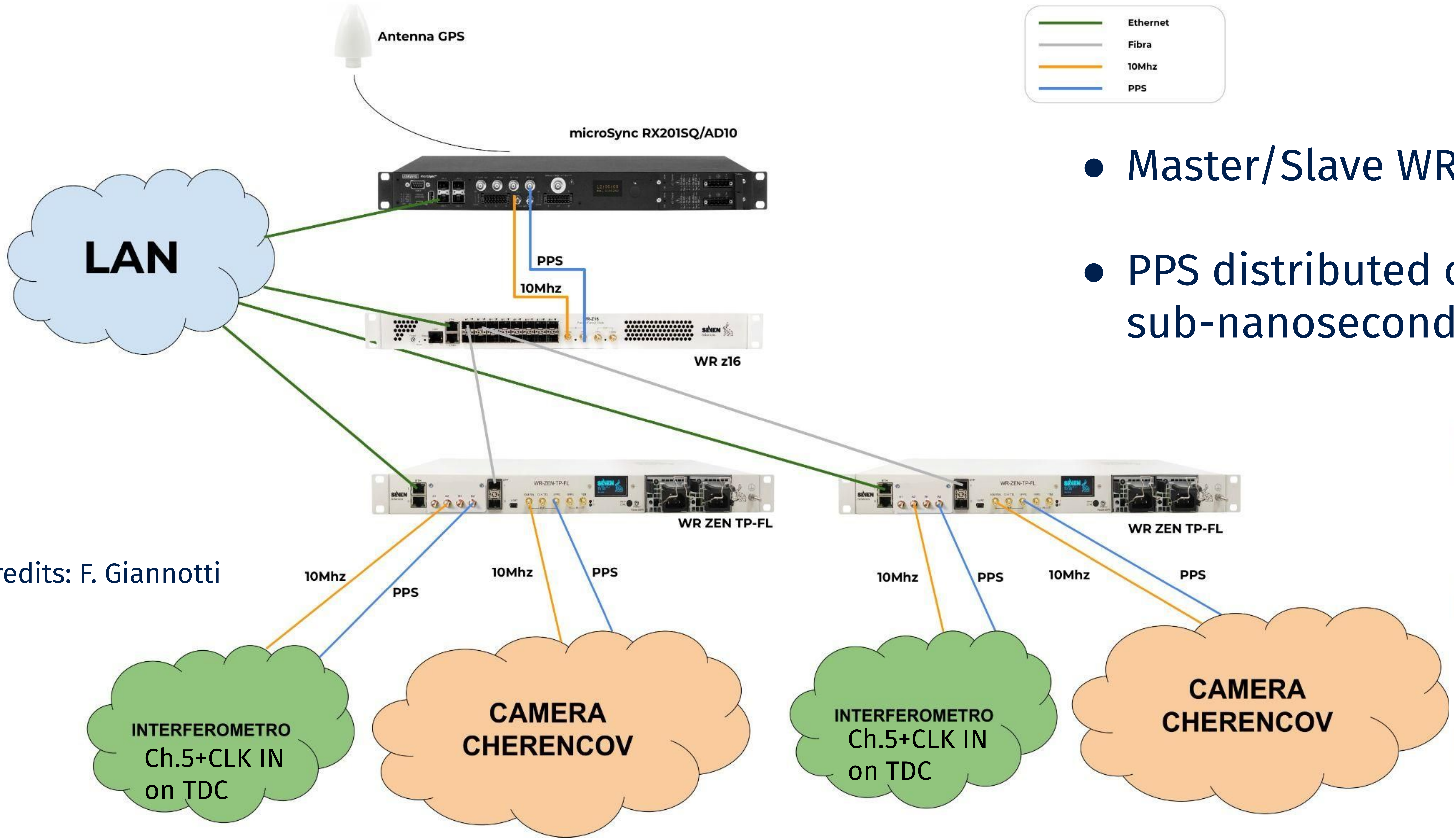




L… r (Asiago) in the Copernico t…

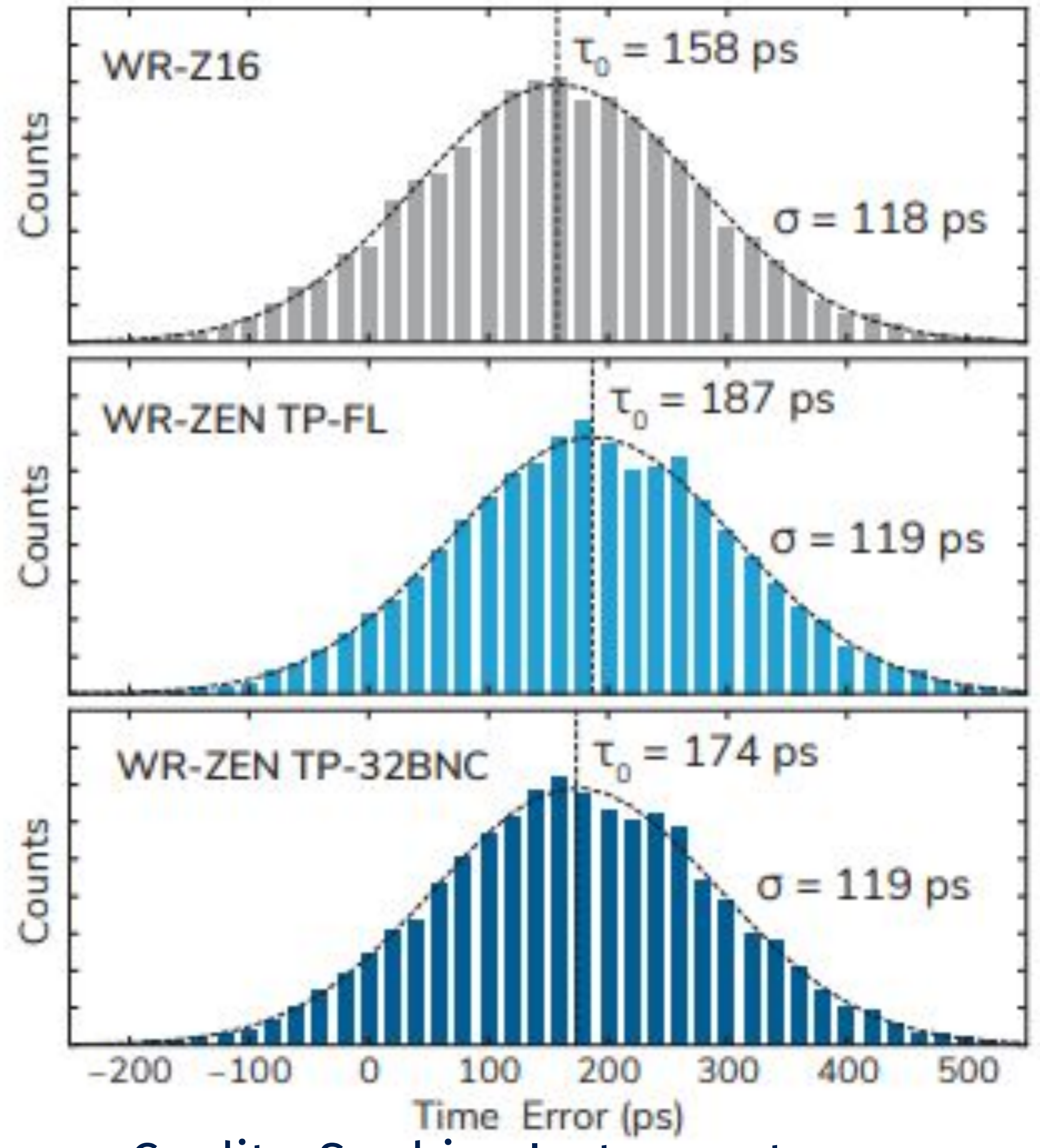
Intensive testing campaign started in 2023. From January 2024 almost every Thursday was dedicated to test

TDU
ASTRI Mini-Array time synchronization system



Credits: F. Giannotti

- Master/Slave WR configuration
- PPS distributed over the network with sub-nanosecond timing accuracy



Credits: Swabian Instrument

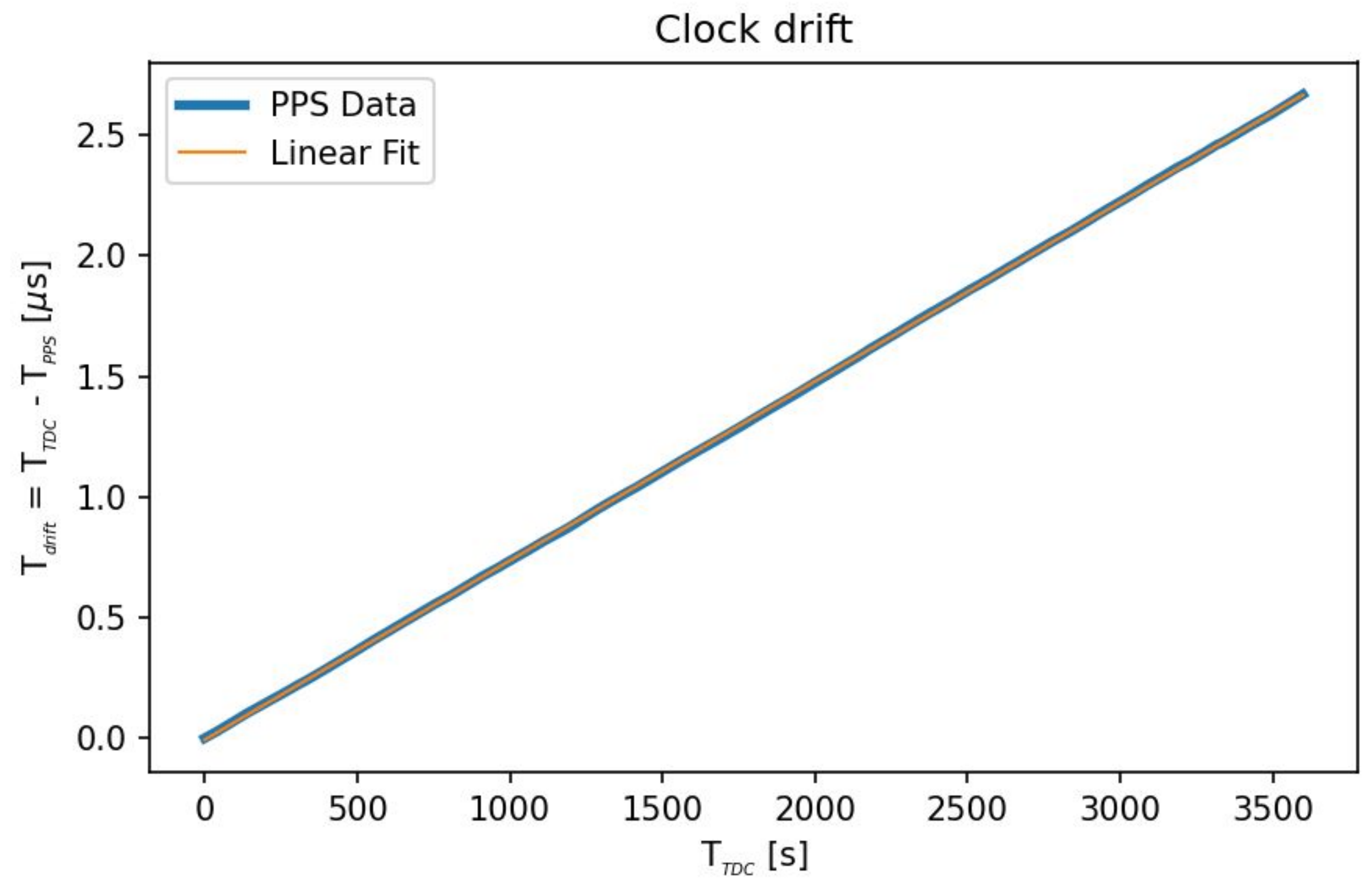
TDU
Time reconstruction algorithm

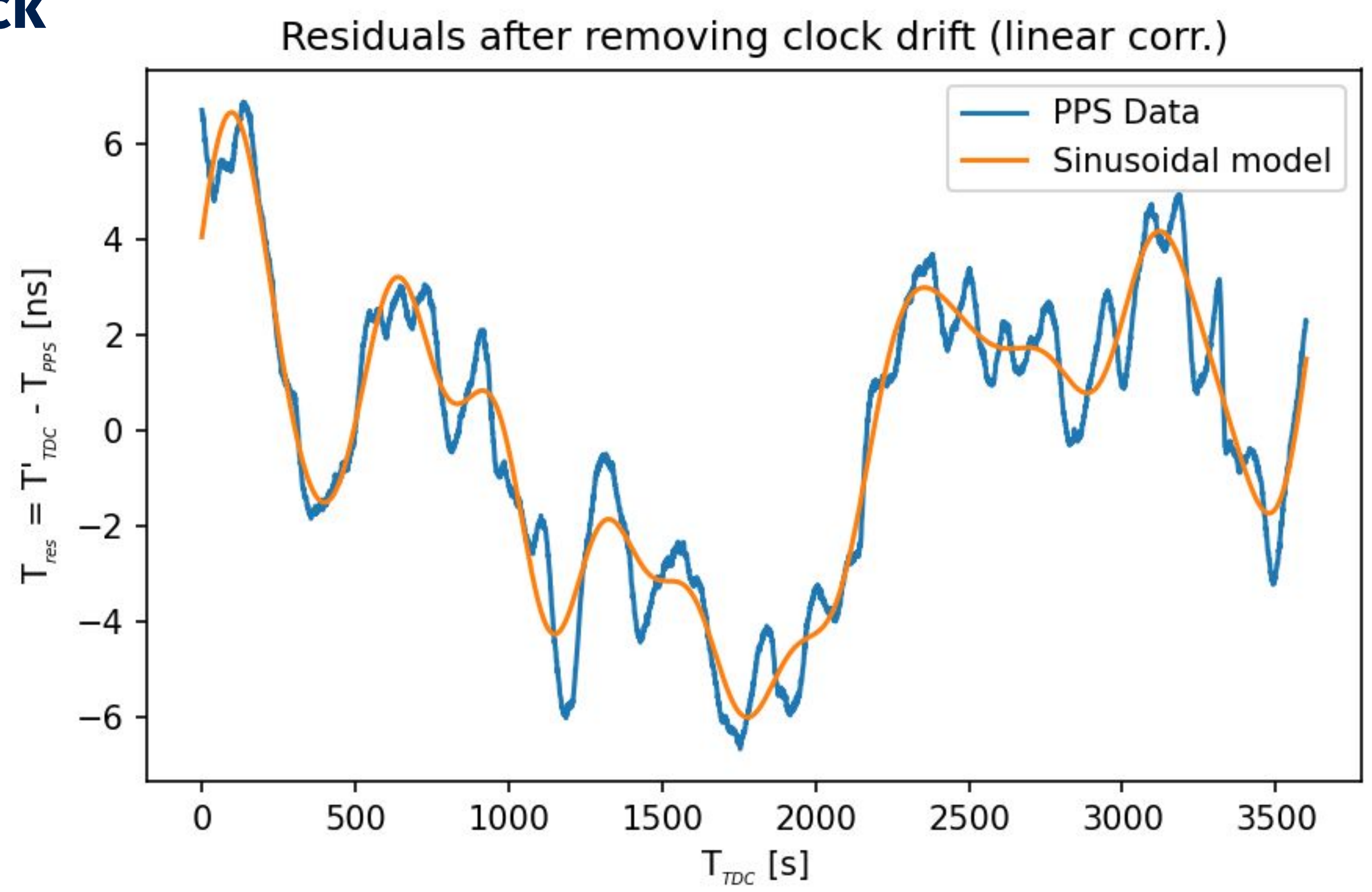
Thunderbolt E GPS (PPS Generator)
Accuracy <15 ns wrt UTC

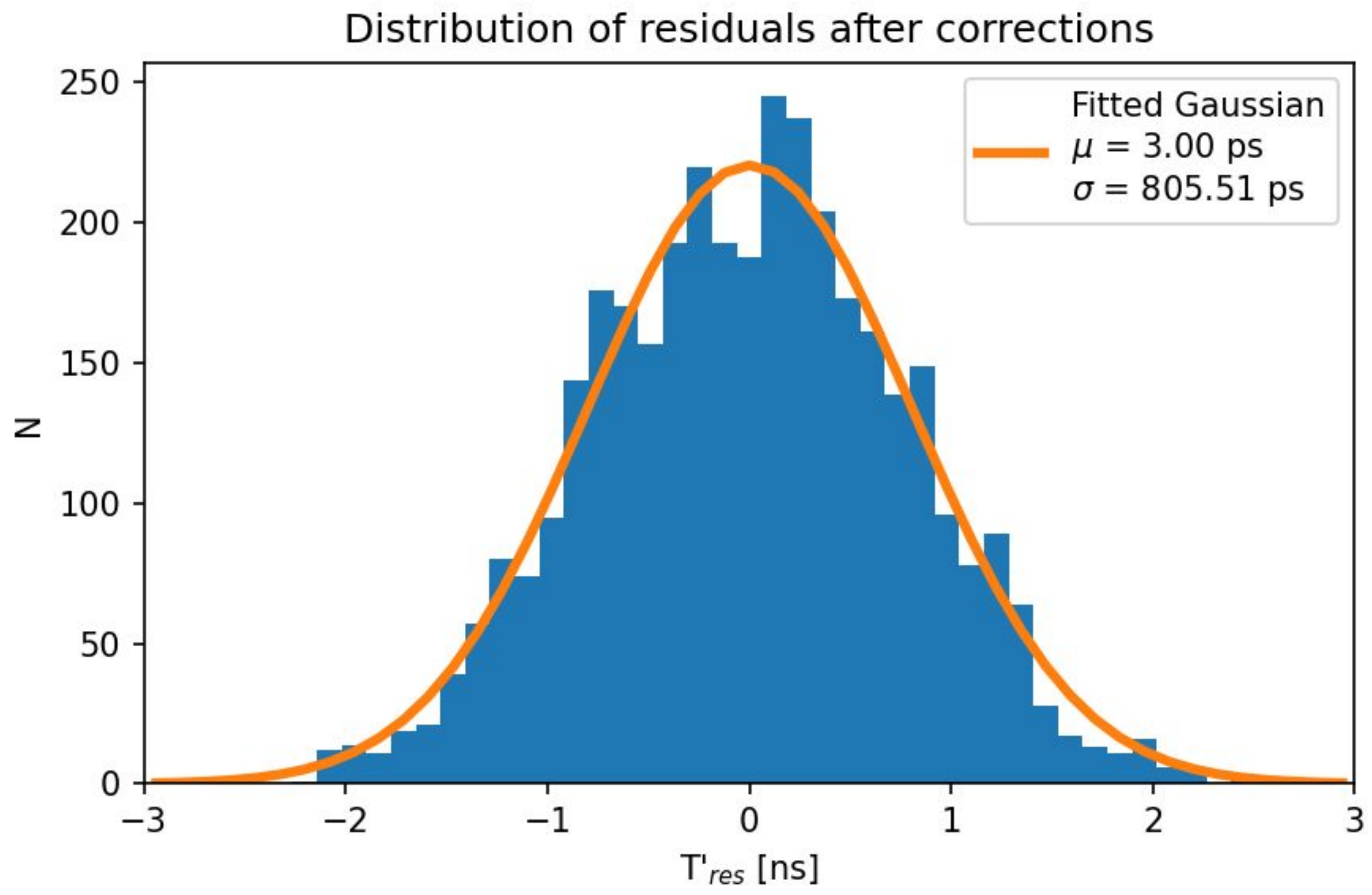
GPS antenna

Rubidium Clock
10 MHz signal

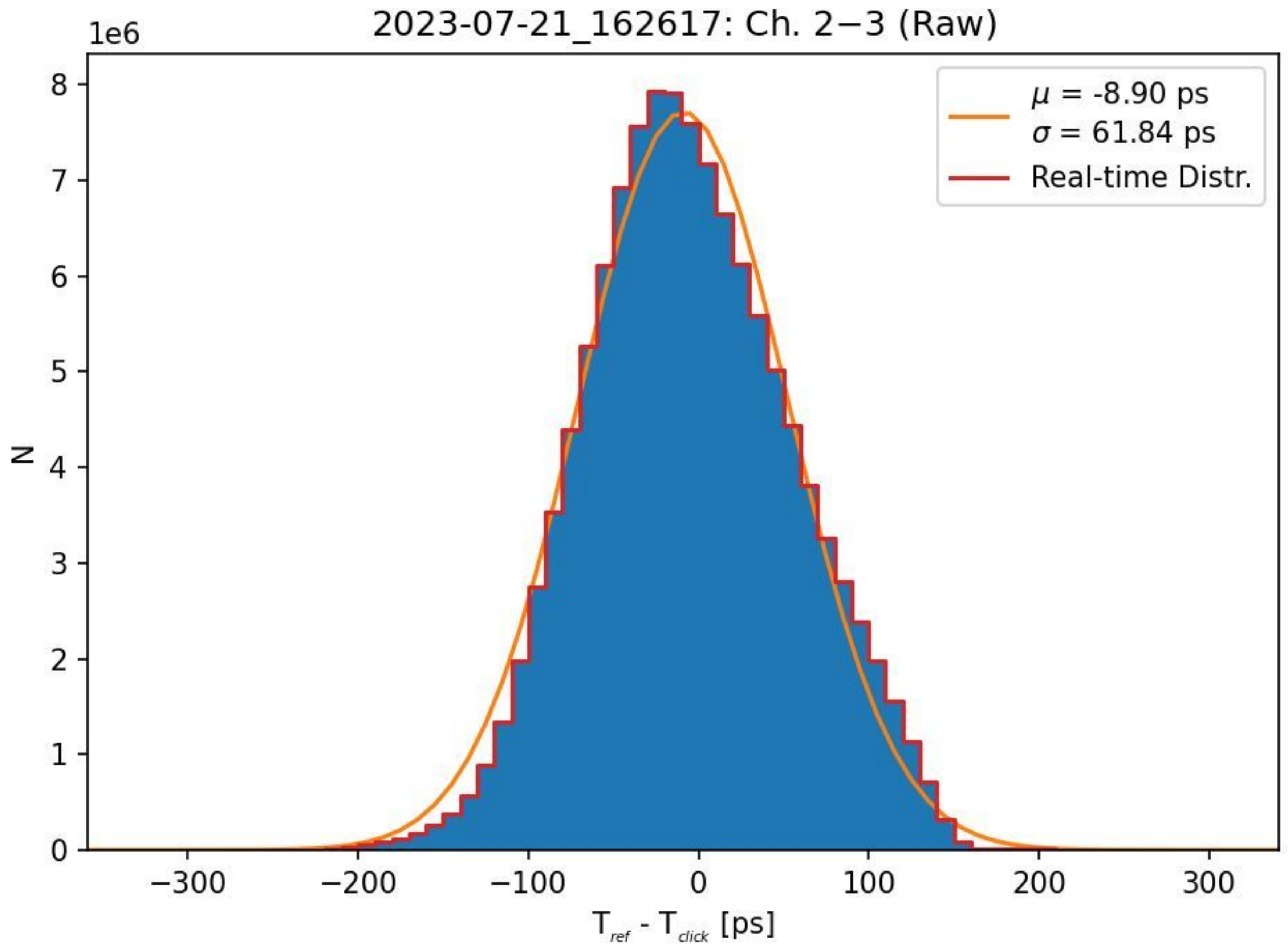
Preliminary test using a low-accuracy PPS generator + 10 MHz signal we could correct the drift of the internal clock of the TDC up to an accuracy <1 ns wrt to UTC.







TDC
Internal Jitter and maximum rate



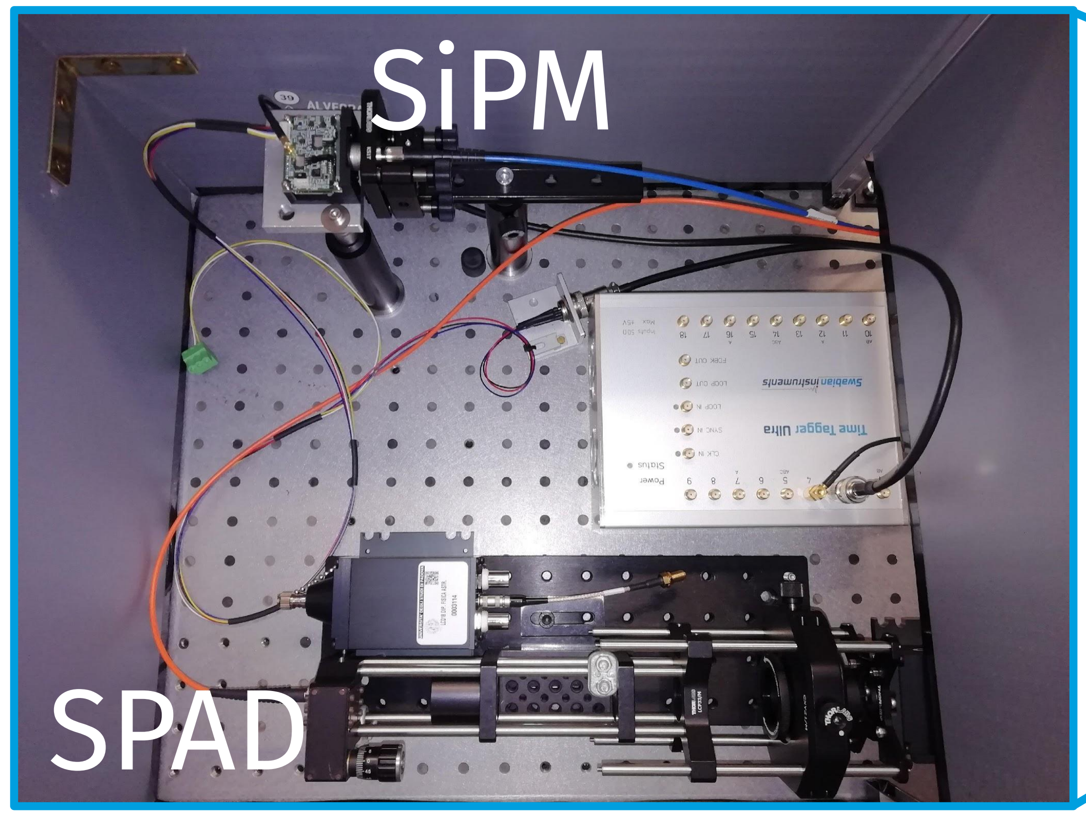
Time tagger internal jitter: 1 MHz square wave (from function generator) splitted in two channels of the TDC. Measuring time of arrival of signal at channels we measured values in agreement with specifications.

Maximum rate: ~80 Mcount/s

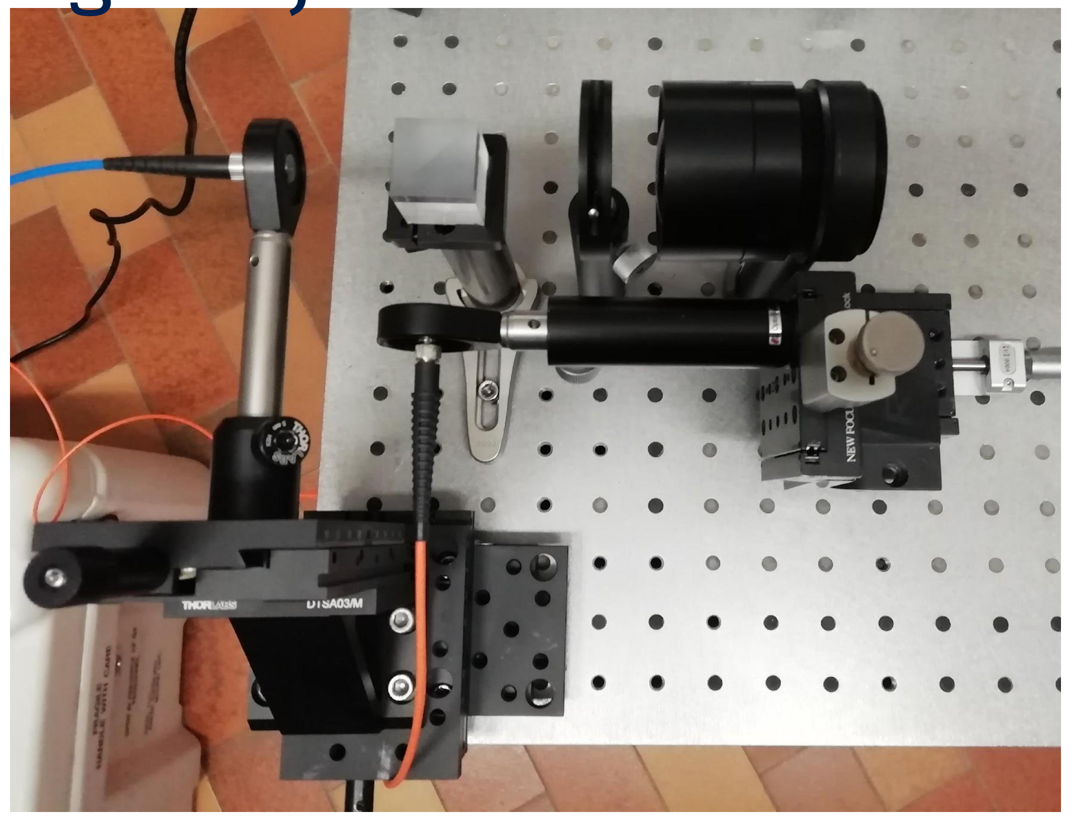
Channel	Jitter (ps)	
	Two Channels	Single Channel
1	61,07	43,18
2	60,47	42,76
3	59,90	42,35
4	59,68	42,20

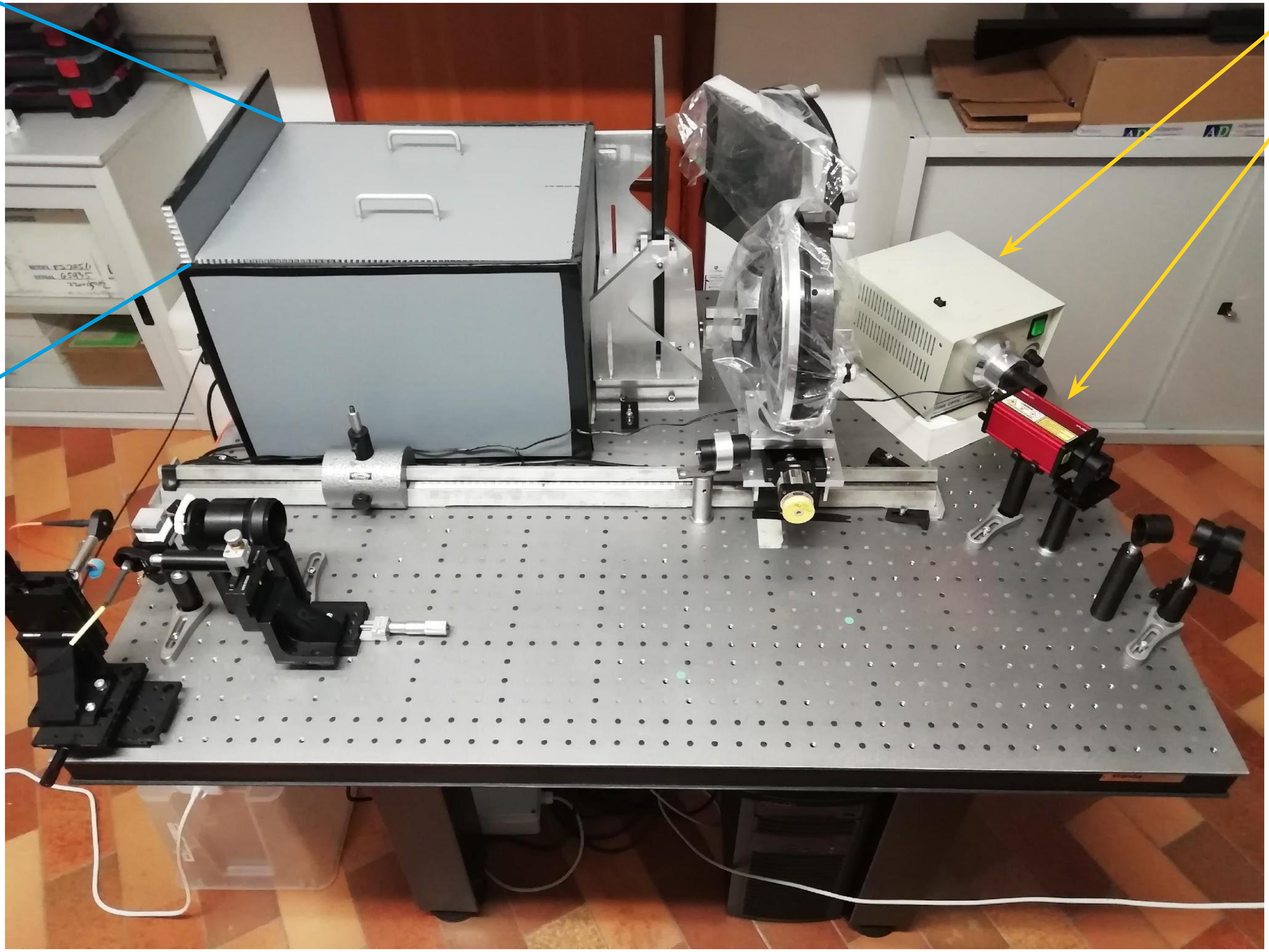
AIV Commercial Detector and Acquisition System
Laboratory Setup for correlation measurements

Assembly-Integration-Verification (AIV) of the commercial SiPM module and the acquisition system in the **ASTRI-AQUEYE laboratory In Asiago (Italy)**.



Light injection Module





Thermal lamp

Nanosecond pulsed laser
1 to 10 MHz repetition rate, ~6ns pulse duration, λ=450nm

Reflecting mirror

Pinhole ~ 100 µm

Focusing lens + Baffle
at 950 mm from pinhole

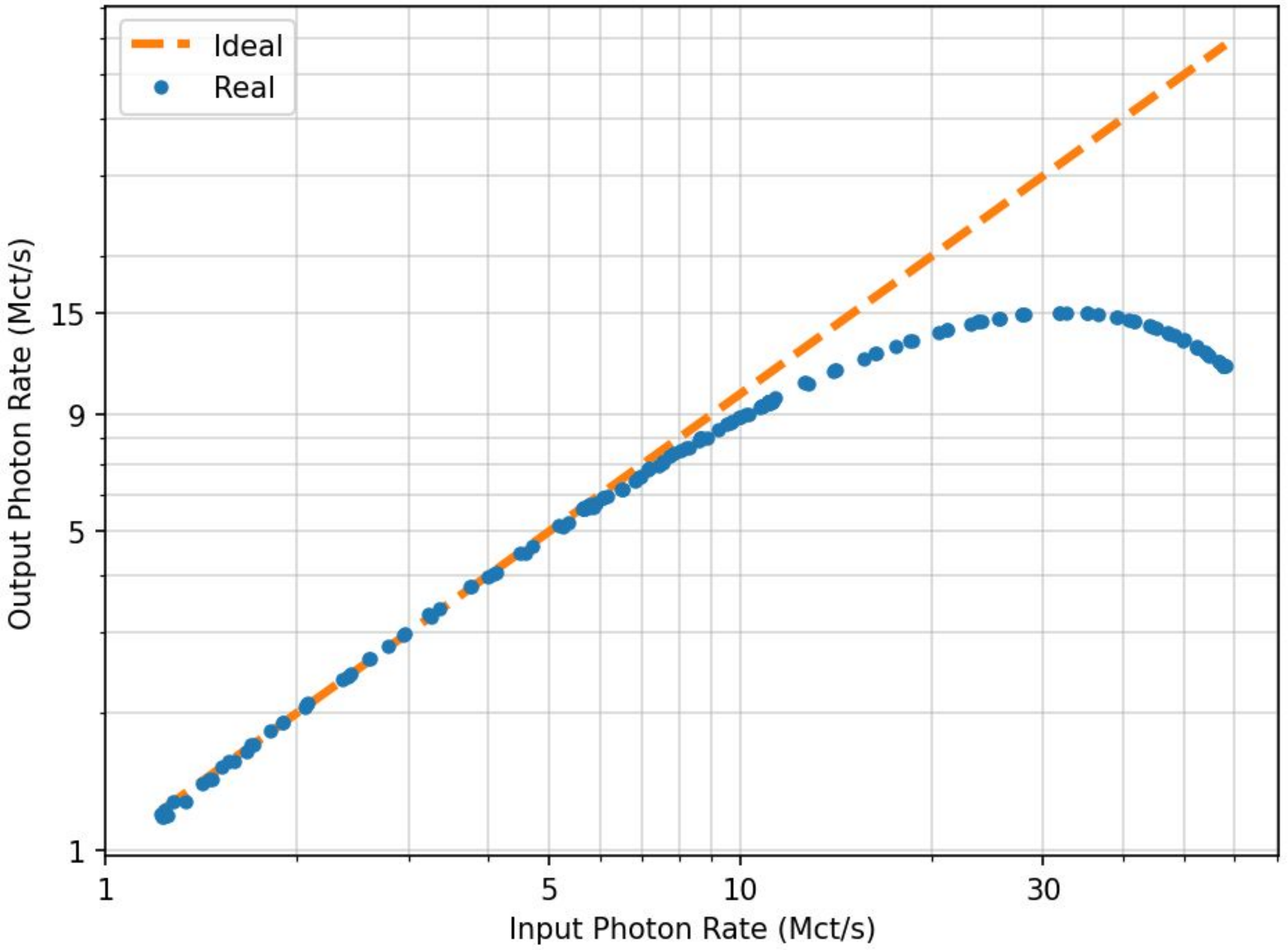
50-50 cube beam splitter

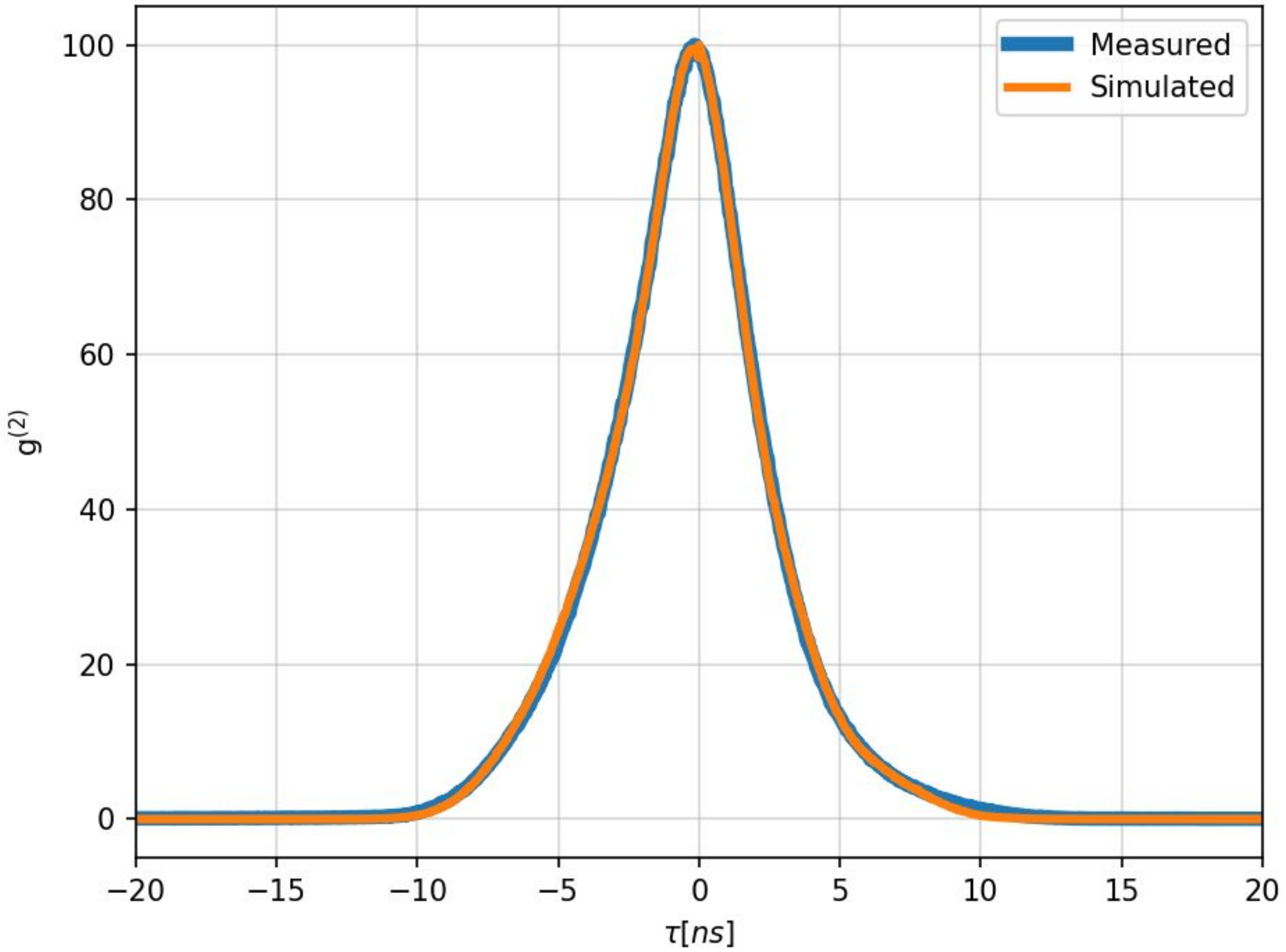
Optical fibers on the two arms feeding a SiPM and a SPAD detector

AIV Commercial Detector
Linearity curve and Jitter

SiPM powered with a **linear stabilized power supply**
[Bel Power AC/DC converter +/- 5V, 15W]

Power cable: **10 m long**
Data cable: **5 m long RG174 coaxial cable**
Booting phase: **~40 seconds**, both status output connectors switch to the 'high' state and the MPPC is active





Linearity: till **~ 10-12 Mct/s**

Max output rate: **~ 15 Mct/s**

Dark rate: **~ 40 kct/s**

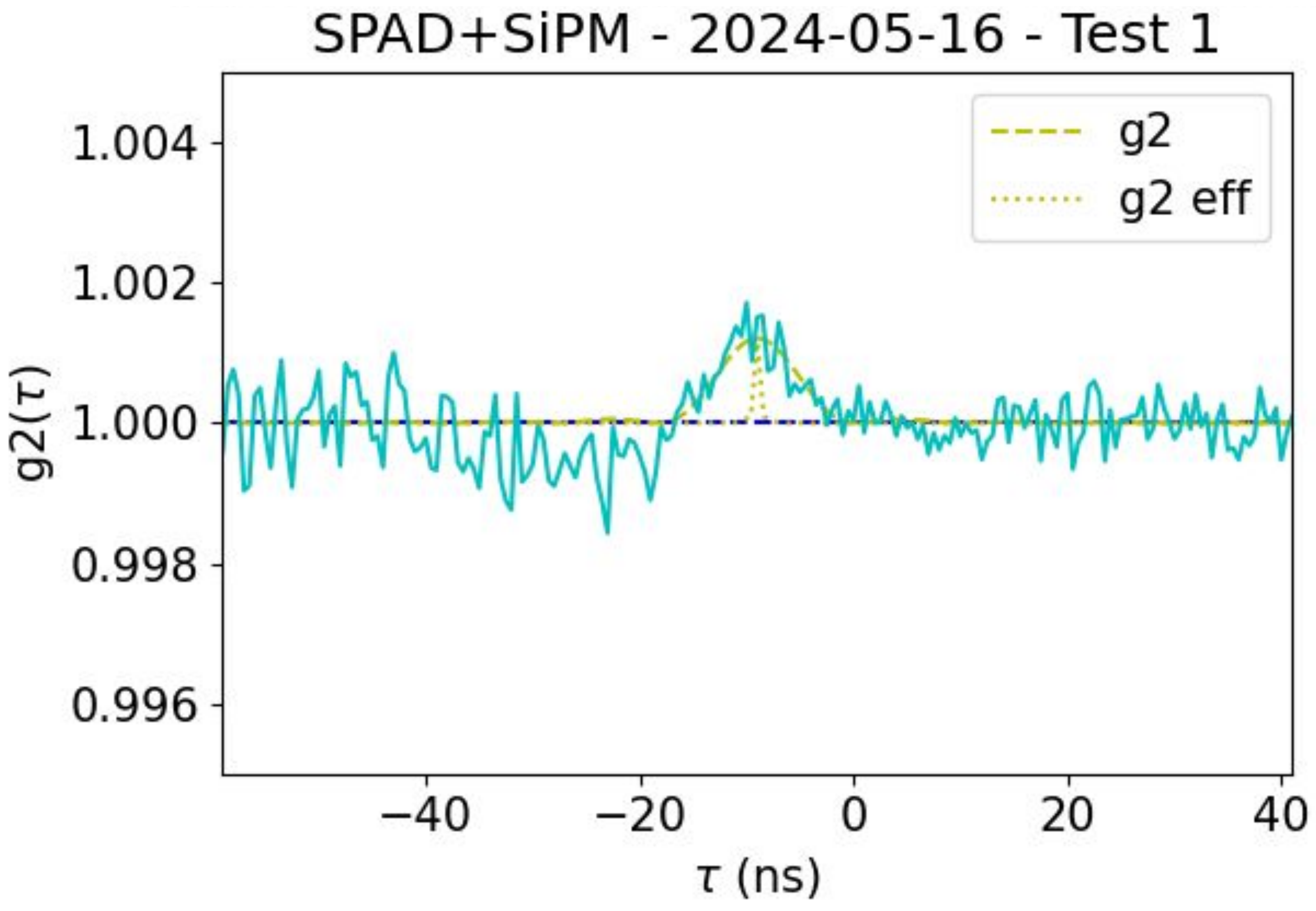
Jitter SiPM: **~ 600 ps** (a factor ~2 higher than that of a SPAD)

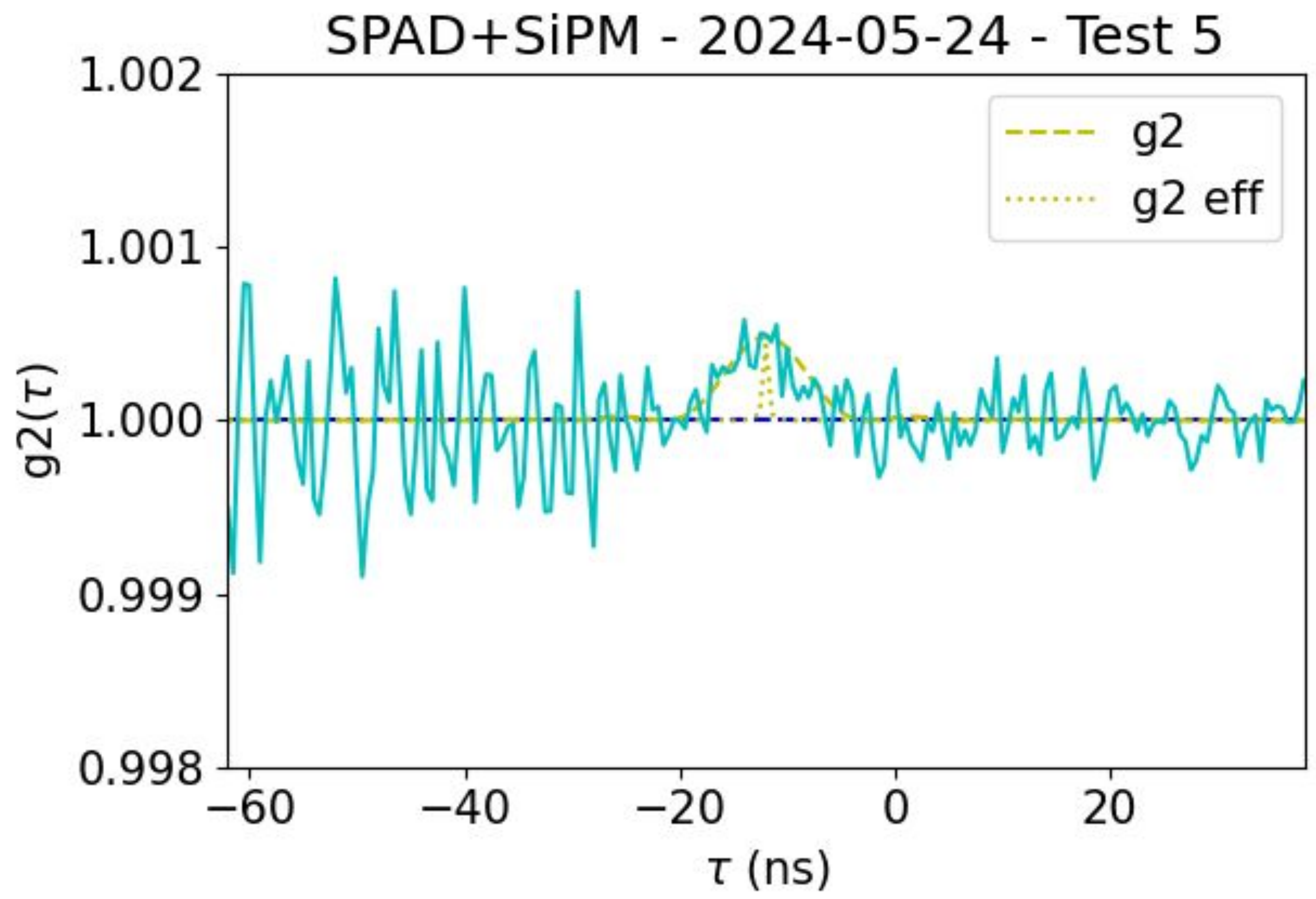
Total jitter: **~ 750 ps**

AIV Commercial Detector and Acquisition System
Correlation Measurements

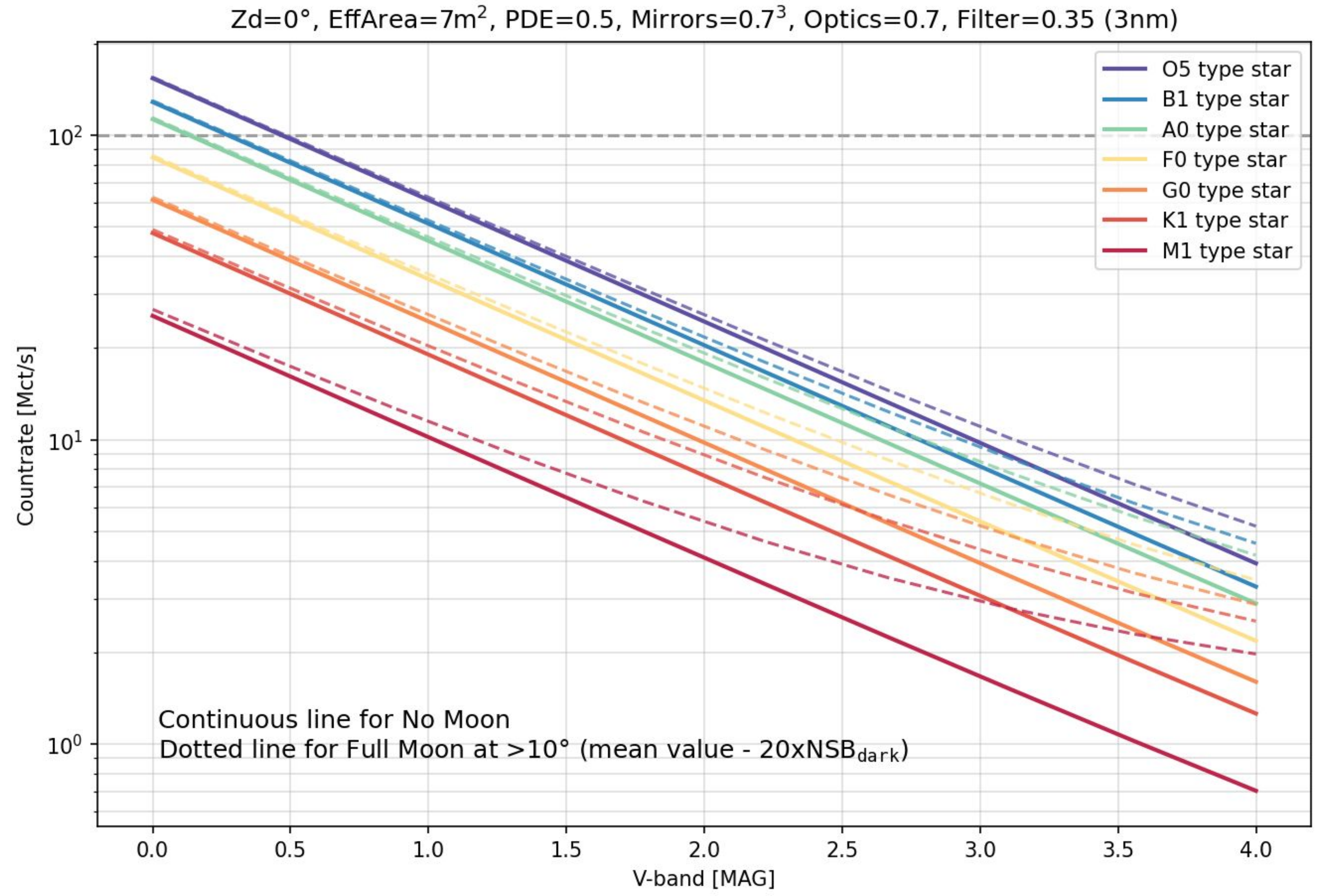
Pinhole illuminated with **thermal lamp and nanosecond pulsed laser**, mimicking a **zero baseline measurement** of a thermal source (with a superimposed ’coherent’ signal). SiPM signal correlated with the TTL output signal of a SPAD.

Delay between the detectors: **~ −10 ns**





	$g^{(2)}$	Exp. s	S/N	Δλ nm	Ctrate Mct/s	Mag
Test 1	1.0012	300	~4	0.75	23.6	0.7
Test 5	1.00043	5400	~4	2.00	13.6	2.4



Captured **electronic noise subtracted** using a **“White Light” acquisition** (acquisition without the “coherent” pulsed signal).
Origin still under investigation.

Residual systematic noise in excess of the Poisson noise remains for negative delays with a root-mean-square (rms) variability at the level of ~ 10^{-4}.

Conclusions

Mini-Array

➔ In 2023 we started **testing all the electronics of SI^3** in a dedicated laboratory.

➔ We tested the **time reconstruction algorithm** with a prototypal version of the TDU: We could already achieve **synchronization to UTC within 1 ns**.

➔ Detector preserves **linearity up to ~10-12 Mcounts/s** and reaches a **maximum output rate of ~15 Mcounts/s**. The **jitter** of the detector and that of the TDC are **~600 ps** and **~100 ps** (FWHM).

➔ **Total jitter** of the system is **~750 ps**.

➔ The **degree of coherence** at zero baseline **well detected**. Residual systematic noise still to be further investigated

Thank you for your attention!

SI^3

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