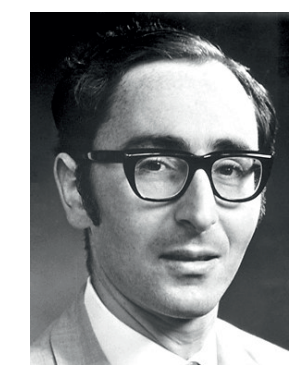


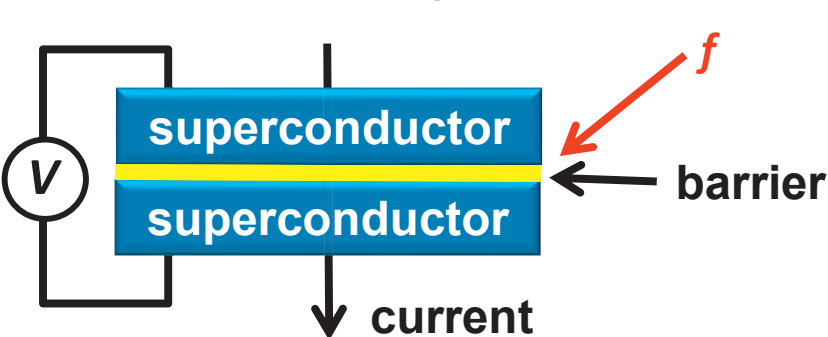
Josephson-based quantum voltage standards - an ongoing success story

Introduction



Brian D. Josephson

Josephson junction



Specific transfer of flux quanta $\phi_0 = h / 2e$ by an external microwave of frequency f results in steps of constant voltage:

$$U_n = n \cdot f / K_J$$

$$1/\phi_0 = K_J = 483\,597.848\,416... \text{GHz/V}$$

Perfect frequency-to-voltage conversion!

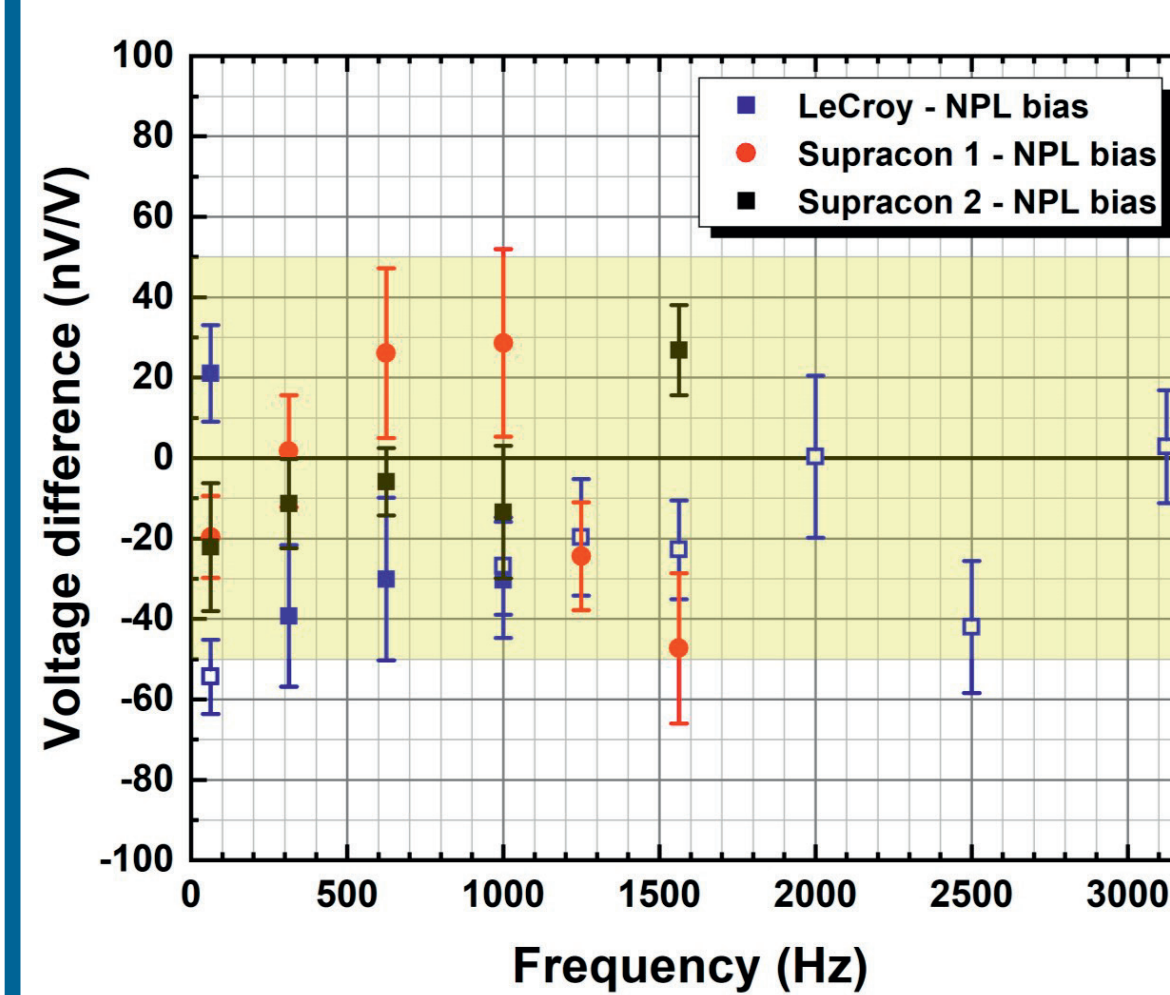
1995 NIST invented Programmable Josephson Voltage Standard (PJVS) and 1996 Pulse-driven Josephson Voltage Standard (JAWS)

- 1962** Josephson effect
- 1963** Shapiro steps
- 1972** BIPM – first Josephson comparisons – K_{J-72} but not unified
- 1984** NIST and PTB made first 1 V SIS array
- 1989** First 10 V SIS arrays
- 1990** K_{J-90} unified worldwide BIPM started onsite DC comparisons
- 2019** Redefined SI: $K_J = 2e/h$ Crucial contribution to h in Kibble balances

AC quantum voltmeter

Introduced: Behr et al. IEEE IM 2007

Comparison example

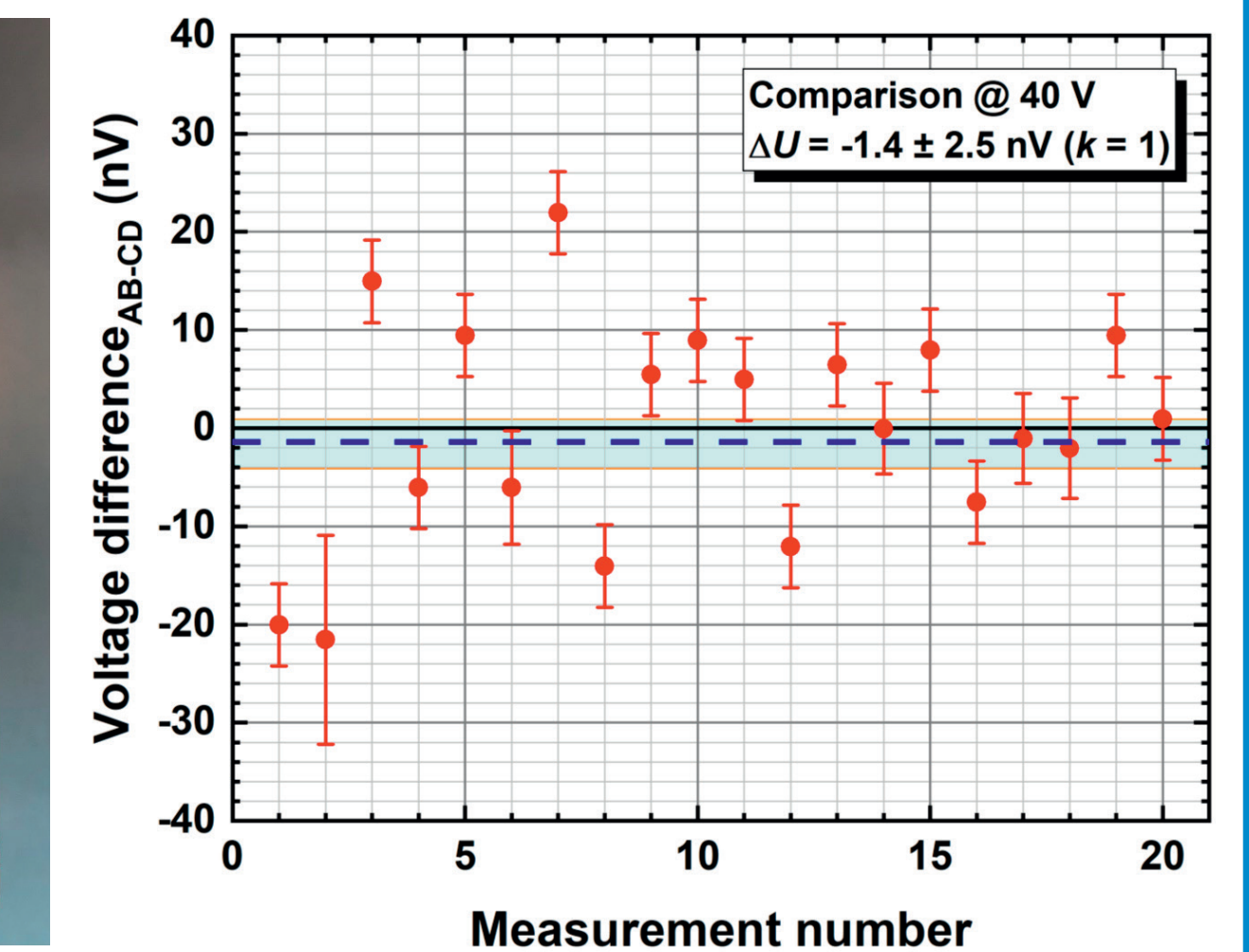
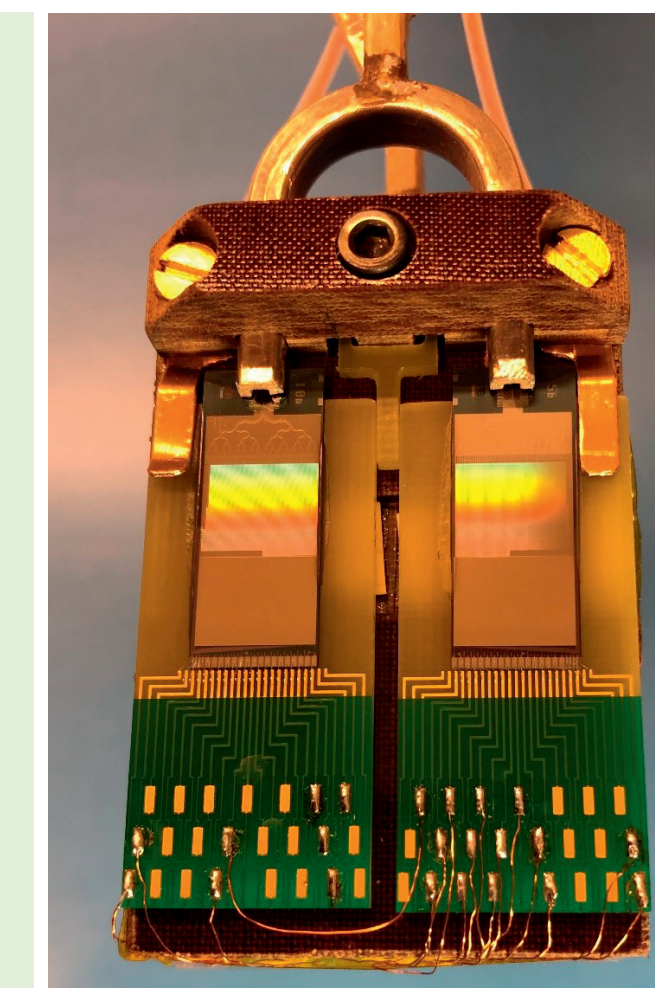


Specifications:

Up to 7.2 V_{RMS} fully automated
10 Hz – 2 kHz [Lee et al. Metrologia 2013](#)
Uncertainty $< 1 \times 10^{-8}$ [Behr et al. Metrologia 2015](#)
Sub-sampling to 100 kHz [Behr et al. Metrologia 2021](#)

DC Josephson standard up to 80 V

- 1997** 1 V PJVS Array
NIST 32 000 JJ
- 2001** 10 V PJVS Array
PTB 69 632 JJ
- 2008** 10 V PJVS Array
NIST 265 000 JJ
- 2012** 20 V PJVS Array
AIST 524 288 JJ
- 2022** 80 V PJVS
4 x 20 V Arrays
PTB 557 000 JJ



Recent PJVS DC applications

- ADC characterization [N. Beev et al. IEEE Trans. IM 73, 6501710 \(2024\)](#)
- Penning-trap source [A. Kaiser et al. Appl Phys. Lett. 124, 224002 \(2024\)](#)
- Quantum current source [S. Djordjevic et al. Nat. Commun. 16, 1447 \(2025\)](#)

1962-96

2006-19

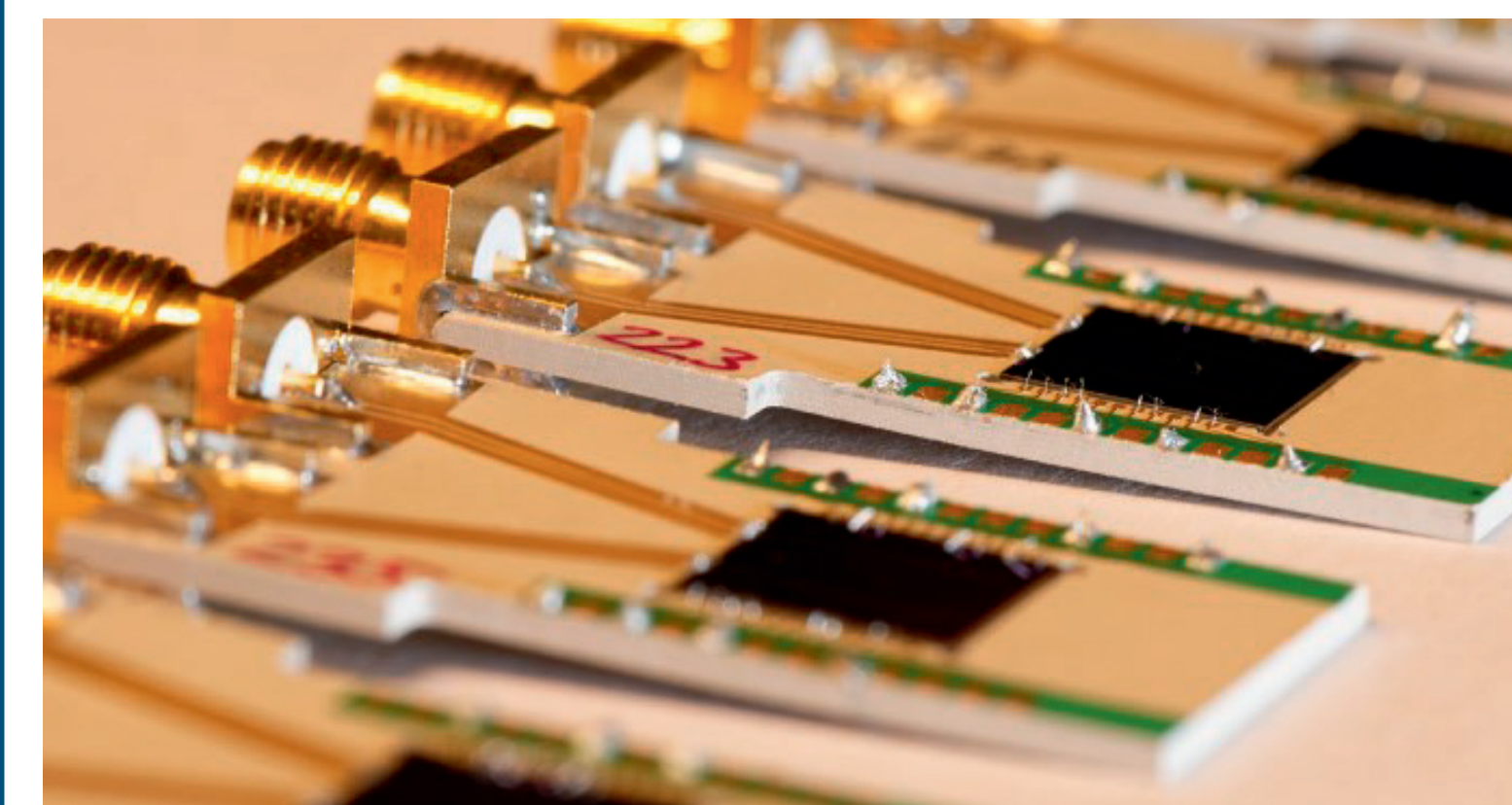
2006-21

2010-23

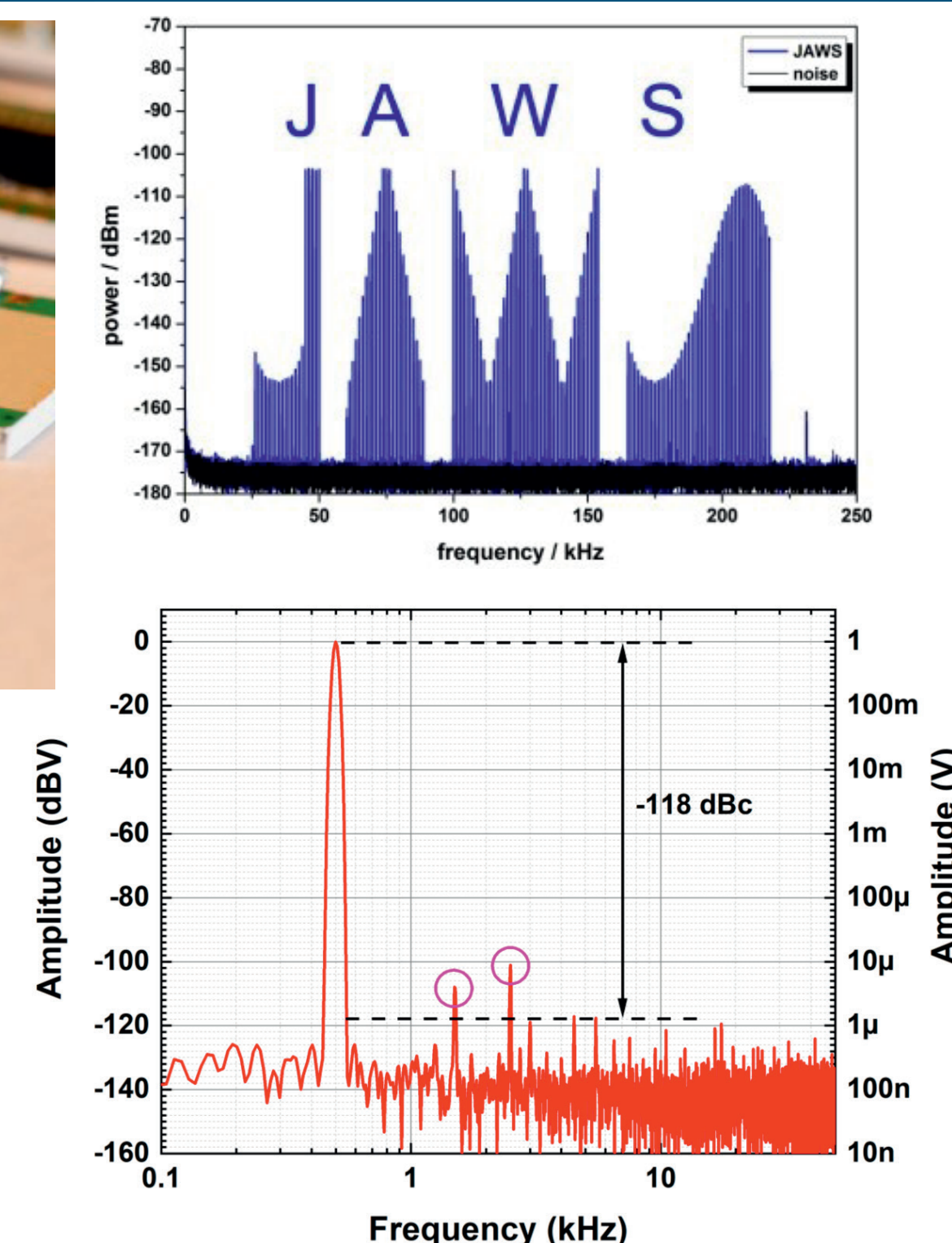
2022

2025

Development of 1 V JAWS

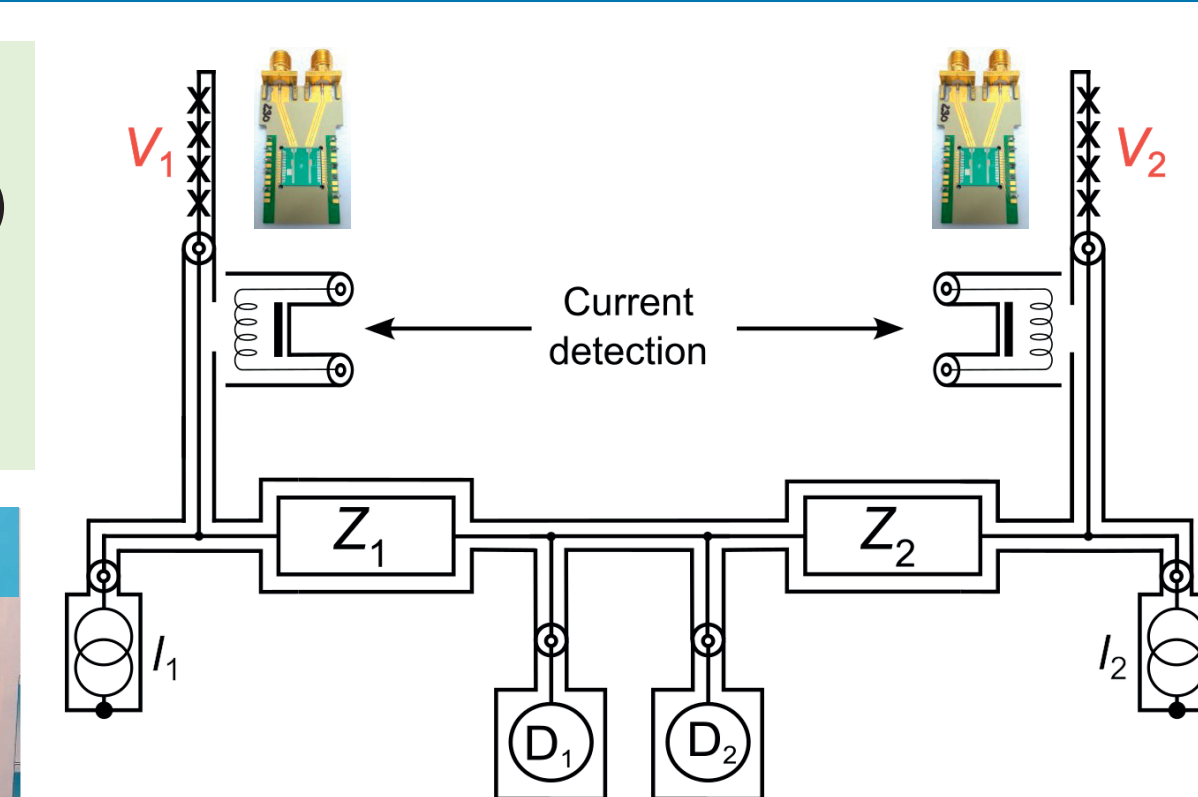
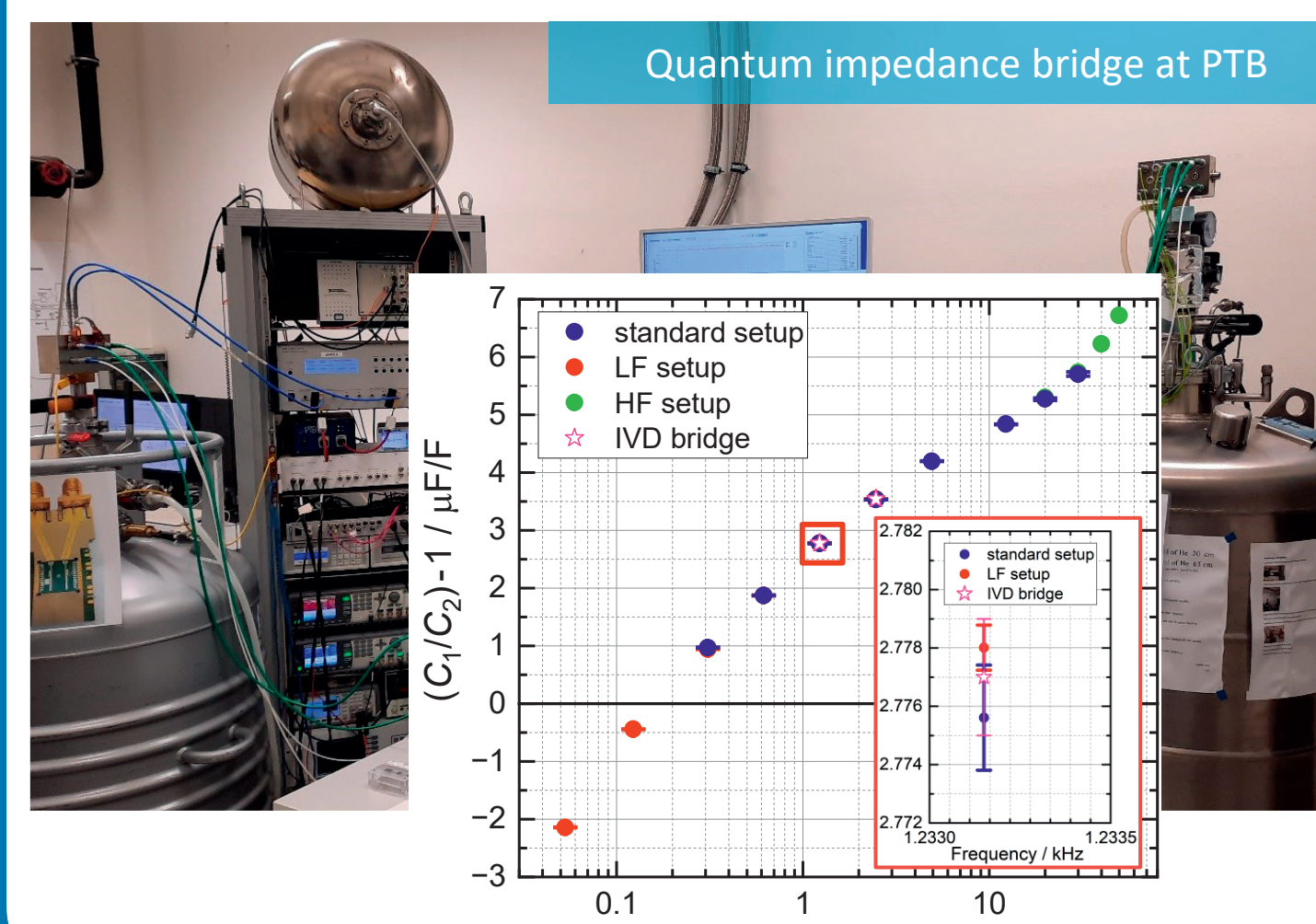


- 2006** 300 mV JAWS (NIST)
- 2014** 1 V JAWS (PTB/NIST)
- 2015** 1 V JAWS-PJVS Comparison (PTB)
- 2019** 4 V JAWS (NIST)



Josephson Impedance Bridges

- 2010** PJVS Bridge (PTB)
- 2016** JAWS Impedance Bridge (METAS/NIST)
- 2017** JAWS Bridge with QHR (PTB)
- 2023** JAWS Bridge comparison (METAS/PTB)

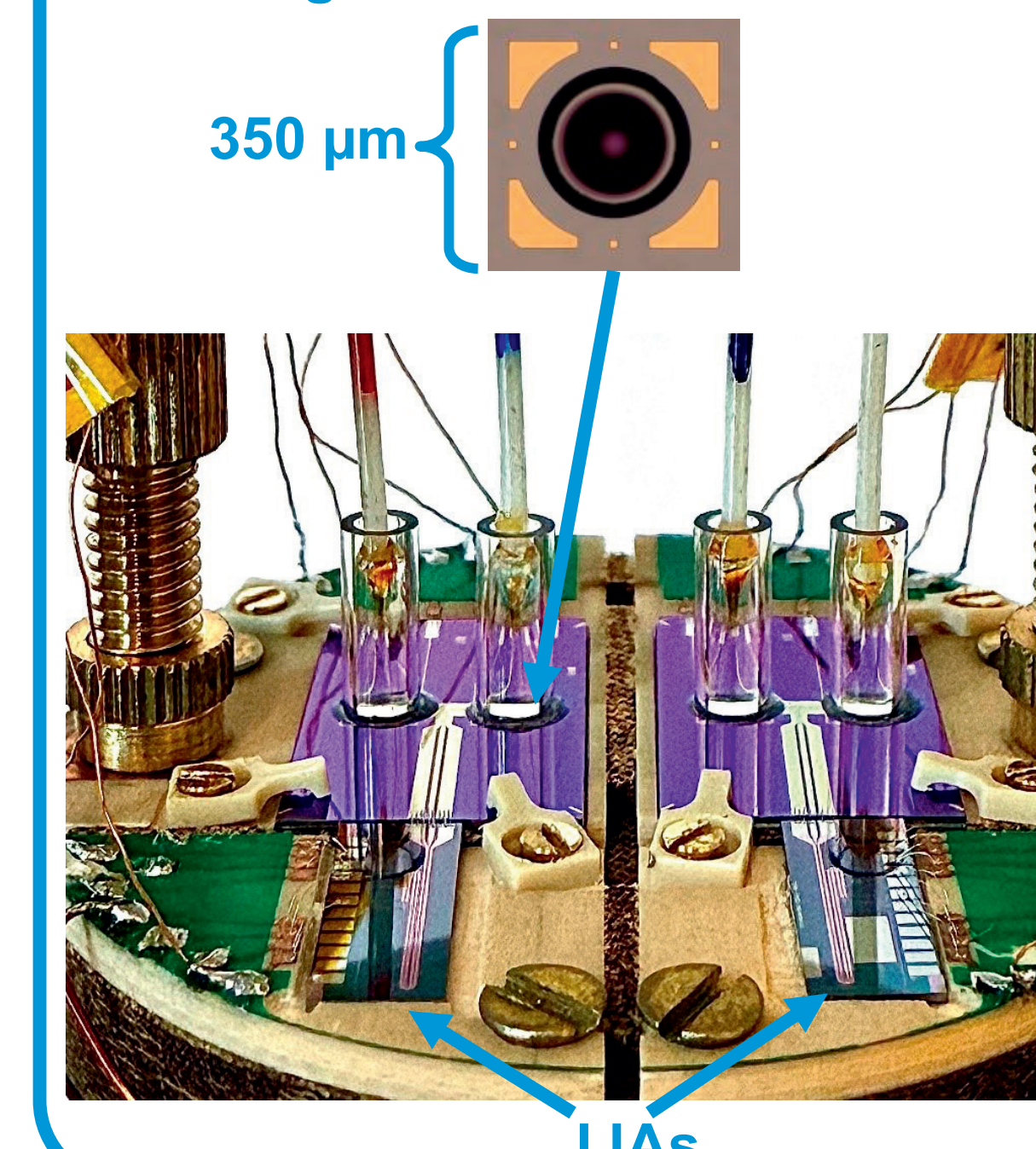


Specifications:

Up to 0.3 V_{RMS}
50 Hz – 80 kHz, fully automated
All kinds of impedance ratios including QHR vs. Z
Uncertainty ($k = 1$): $2 \times 10^{-9} - 5 \times 10^{-8}$

Optical pulse-drive for Josephson voltage standards

InGaAs PD with integrated backside lens



Idea: Illumination of paired cryogenic photo-diodes (PD) with optical pulses to drive a nearby Josephson junction array (JJA)

