

## Introduction: The redefinition of the International System of Units

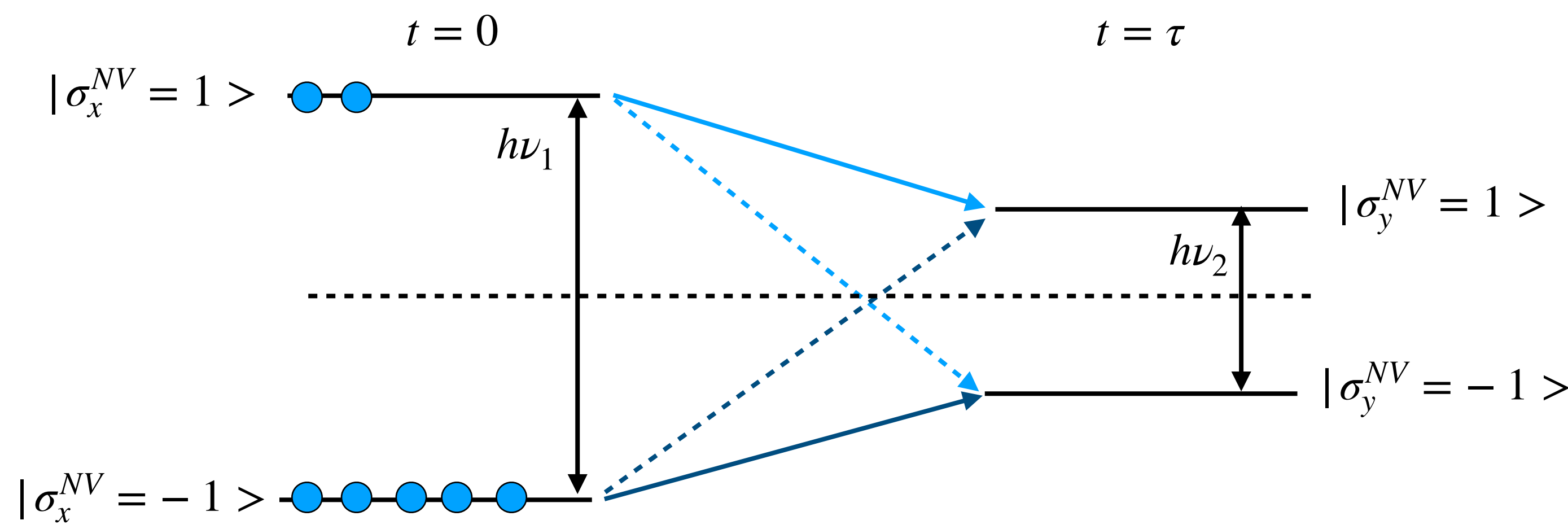
The recent redefinition of the International System of Units in 2019 fixes the numerical values of seven defining constants and links the definition of the seven fundamental units to them. Specifically, the fundamental constant related to the definition of the measurement unit for thermodynamic temperature (the kelvin) is the Boltzmann constant  $k_B$ . We propose a quantum method for measuring  $k_B$  at low temperatures (C), based on the measurement of work distribution (B) for forward and backward (time-reversed) driving using an interferometric technique (A). This method involves the measurement of work distribution at discrete values of the work performed, following the spirit of quantum metrology.

## (B) Results: Work performed for Forward and Backward protocol

The work  $W$  done on a system of finite size and in contact with a thermal reservoir is a stochastic variable, following a probability distribution.

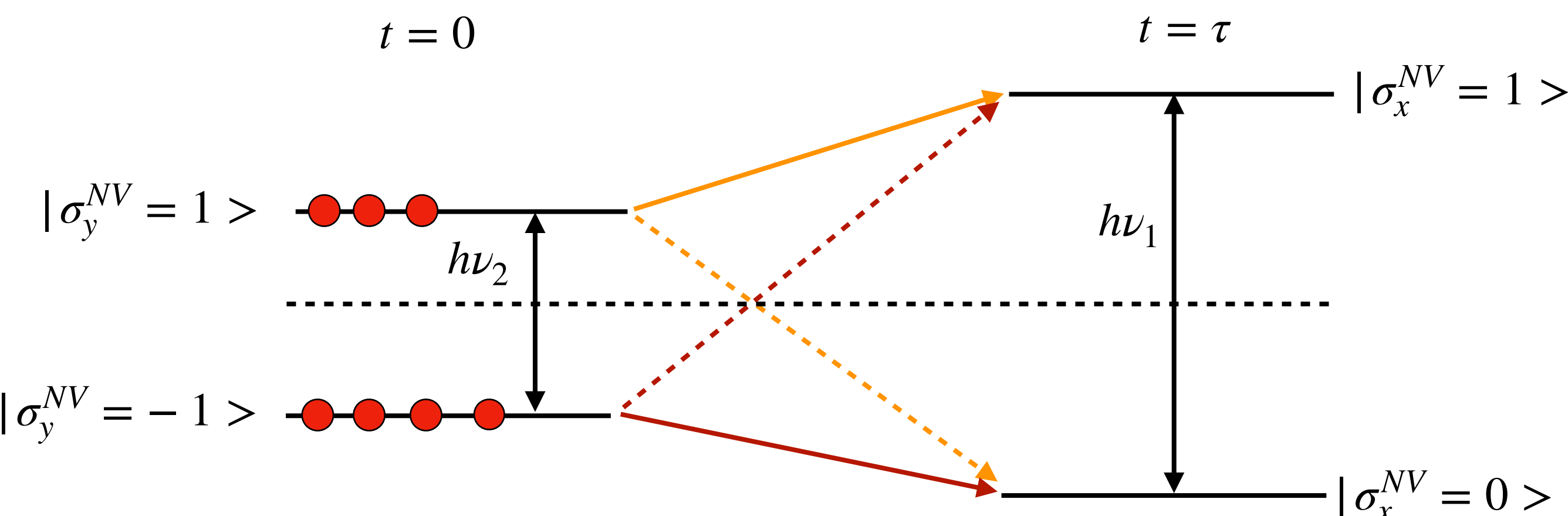
### Forward Protocol

In a fixed time  $\tau$ , the direction of the resonant field axis is changed from  $x$  to  $y$ , and the resonant field intensity is changed inducing the variation  $\nu_1 \rightarrow \nu_2$  on the Rabi frequency. The work performed follows the probability distribution  $P_F(W)$ .



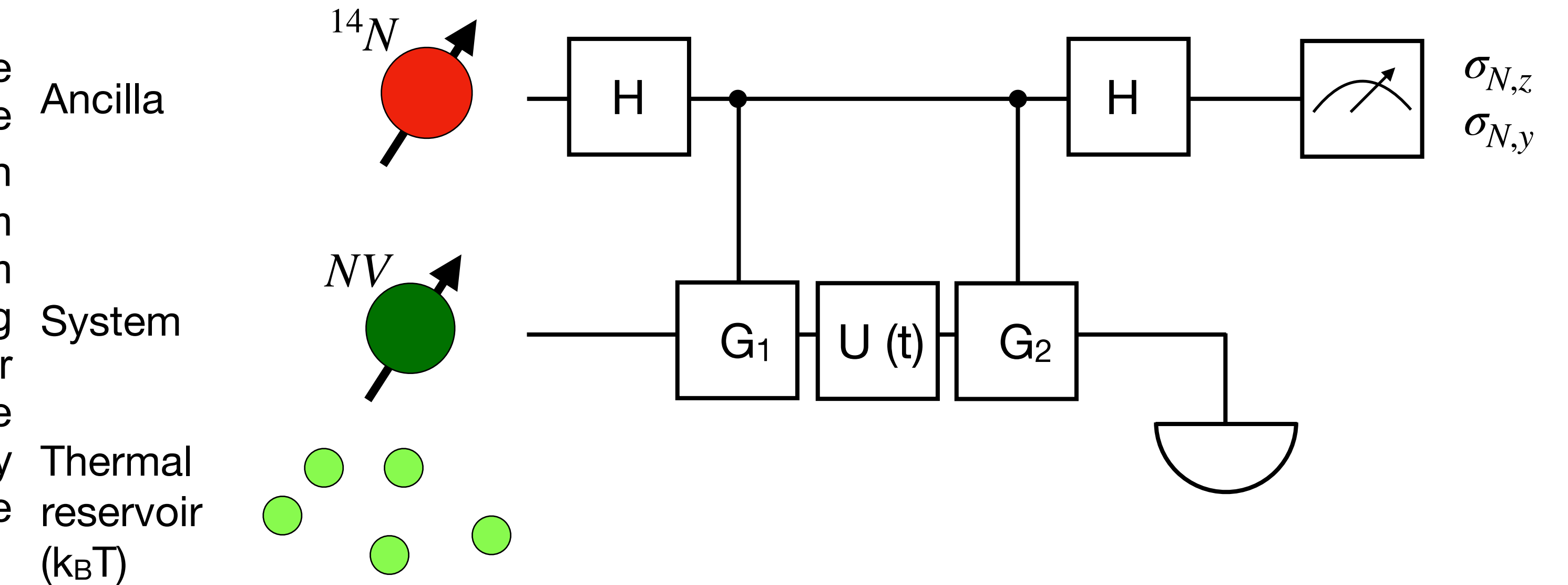
### Backward Protocol

Same as the forward one, but with  $y \rightarrow x$  and  $\nu_2 \rightarrow \nu_1$ ,  $W$  follows the probability distribution  $P_B(W)$ .



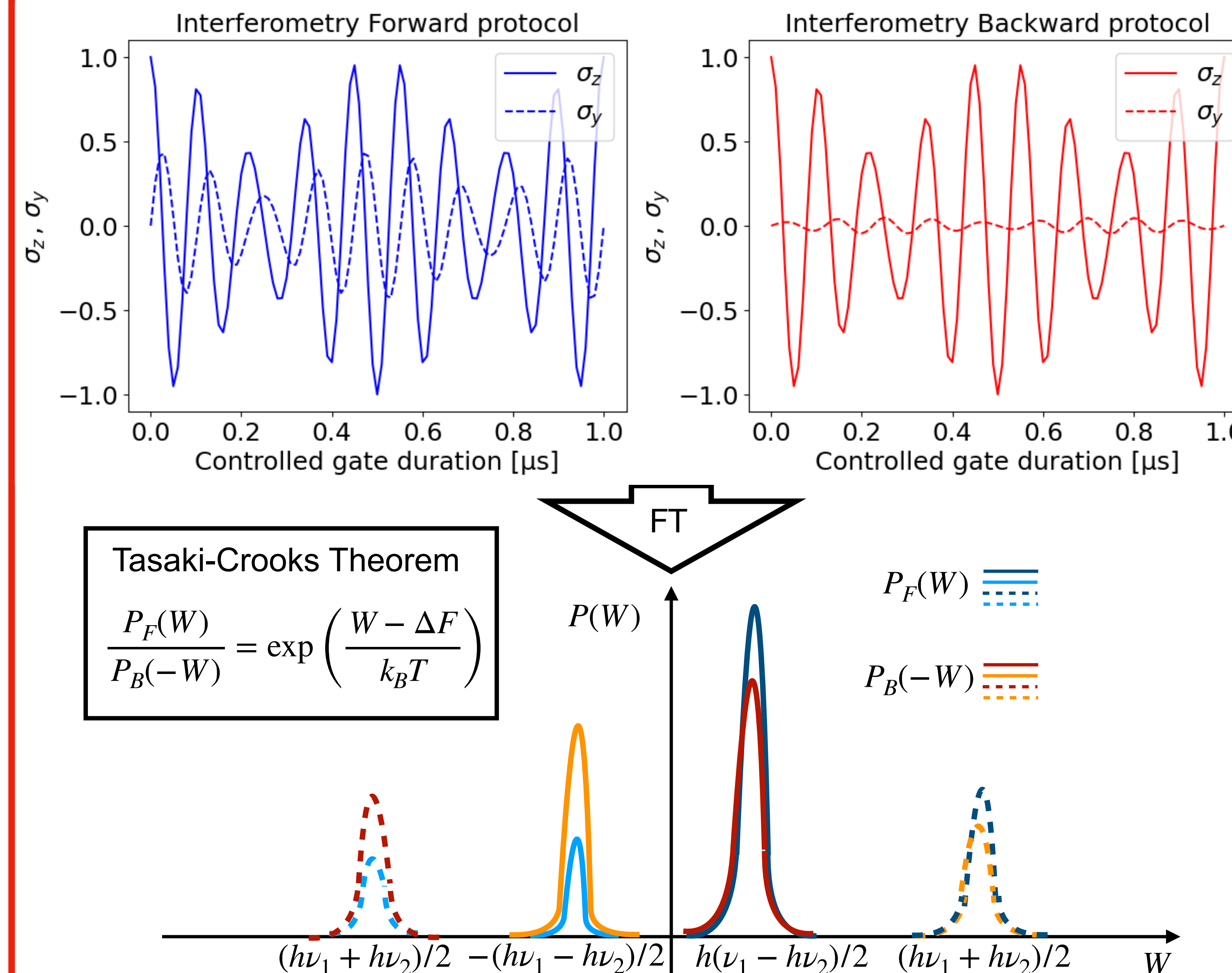
## (A) Idea: Interferometric technique for measuring the performed work

To measure the distribution of the work done by a driving protocol  $U(t)$  on the system, the Nitrogen-Vacancy(NV) center, we will use a modified Ramsey-type sequence. The system is prepared in a thermal state at temperature  $T$ . An ancilla Q-bit, the Nitrogen spin neighbouring the NV, is prepared in a quantum superposition using a Hadamard gate (H). The ancilla interacts with the system through controlled gates  $G_1$  and  $G_2$ , interleaved by the application of the driving  $U(t)$  on the system. Finally, a second H gate acts on the ancilla before its nuclear spin is measured. The information on the work distribution is embedded in the magnitude of the interferometric oscillations of the ancilla spin at precisely known frequencies[1,2,3]. Work on the NV center is obtained by varying the intensity and direction of an oscillating magnetic field[4].



## (A) + (B) Results: Measurement of the Distributions of the Work Performed

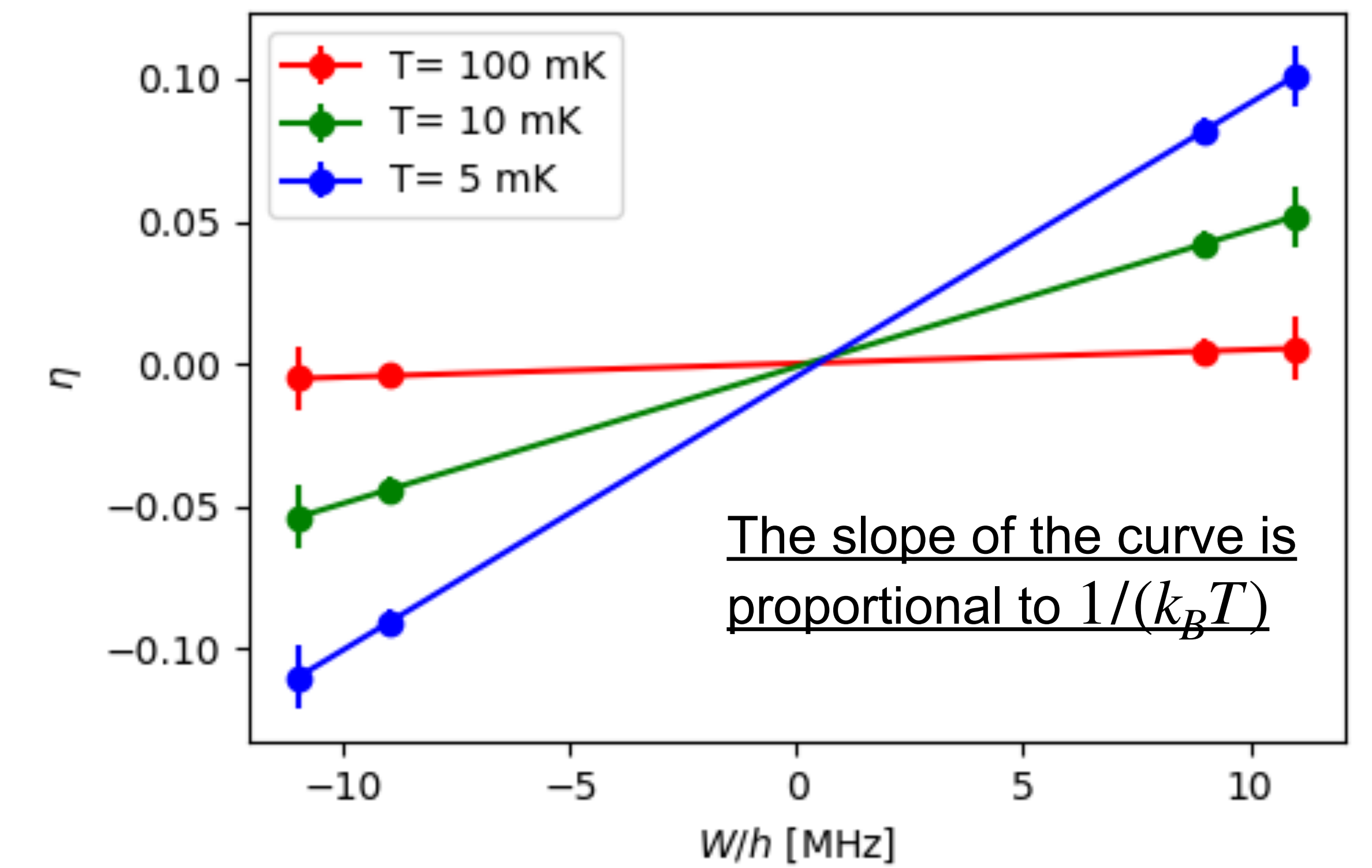
Measuring the ancilla populations ( $\sigma_{N,z}$ ) and coherences ( $\sigma_{N,y}$ ) allows reconstructing  $\chi_F(s)$ ,  $\chi_B(s)$ , i.e. the Fourier transform of the work distributions  $P_F(W)$  and  $P_B(W)$ .  $\sigma_{N,z}$  is related to the real part of  $\chi(s)$  and  $\sigma_{N,y}$  to the imaginary part of  $\chi(s)$



Specific scenario:  $P_F(W)$  and  $P_B(W)$  composed of four Lorentzians, centered on the same value of  $W$  for  $P_F(W)$  and  $P_B(-W)$  and corresponding to the related transition in section (B). The Tasaki-Crooks theorem relates the peak values of each pair of Lorentzians, at a given temperature  $T$  and for a free-energy variation  $\Delta F$ .

## (C) Results: Measurement of $k_B$ at low temperatures

The Crooks-Tasaki theorem predicts a linear relation between the quantity  $\eta = \log(P_F(W)/P_B(-W))$  and the work performed  $W$ . Given that the new SI of Units is based on a fixed value of  $k_B$ , fitting the straight line relating  $W$  and  $\eta$  grants a direct estimation of  $T$ , like a primary thermometer allowing for the realization of the kelvin. The method performs better at low temperatures. At 10 mK we estimate a relative uncertainty of  $u(T)/T = 7\%$ . For comparison, the PLTS-2000 scale has a relative uncertainty of 0.3 % at 25 mK and of 2 % at 0.9 mK [5].



## Conclusions

We proposed a primary method for extracting  $k_B$ , particularly suited for low temperatures. We described the interferometric protocol for measuring  $W$  and reconstructing its probability distribution, linked to the system temperature  $T$  by the Tasaki-Crooks theorem. We estimated the relative uncertainty at low temperature to be about one order of magnitude bigger than the one estimated for standard methods.