Tutorial on Error Mitigation

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Recall the noise model…

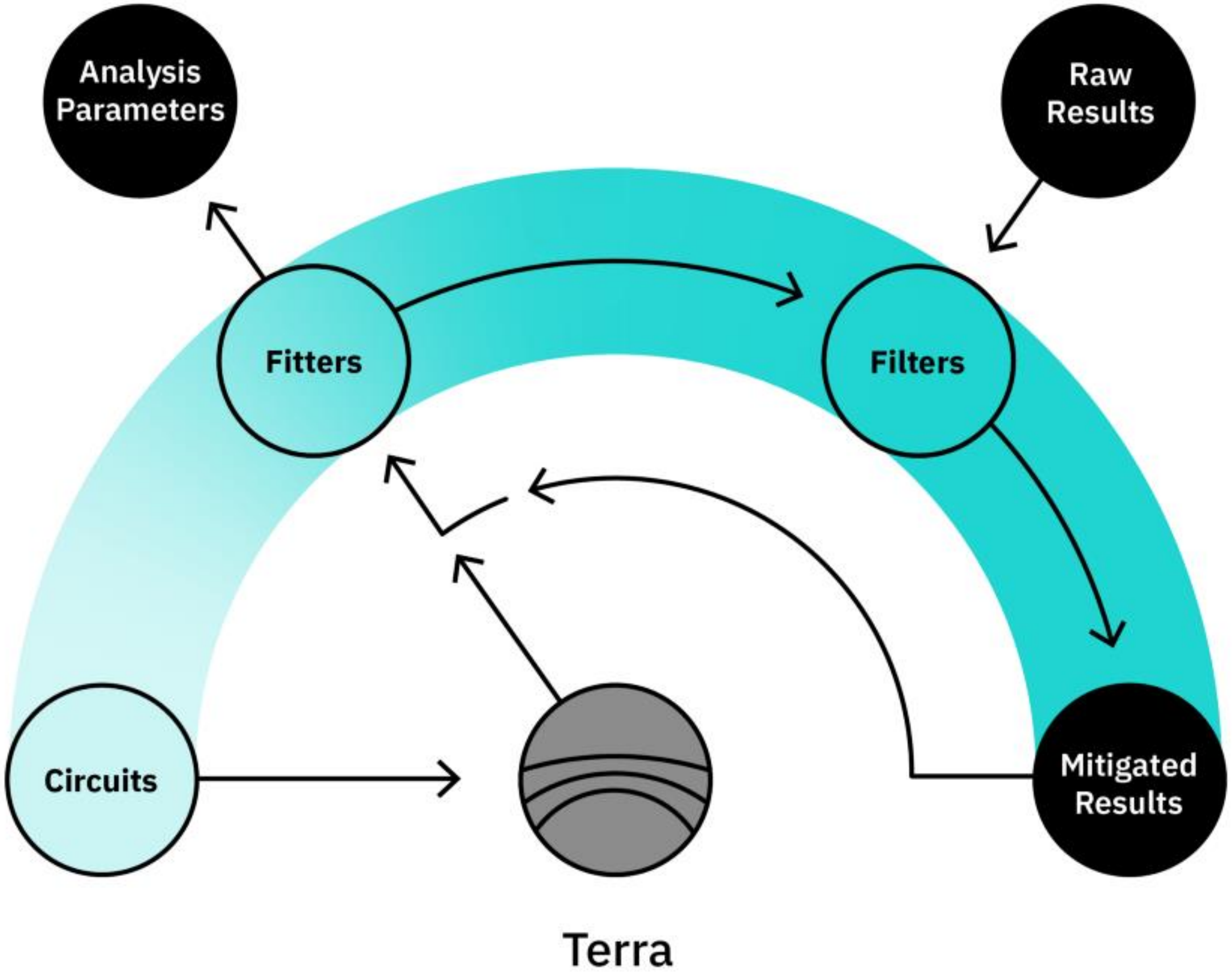
For the readout errors the probability that the recorded classical bit value will be flipped from the true outcome after a measurement is given by the qubit *readout_errors*.

In the following, we focus on dealing with measurement errors.

Qiskit-Ignis

Understanding and mitigating noise in quantum devices.

Ignis framework



Qiskit Ignis sub-module structure

- **Circuit** functions:

  Build circuits to perform desired characterization / mitigation(減輕) / verification

- **Fitter** classes:

  Analyze and interpret results of these circuits

- **Filter** class:

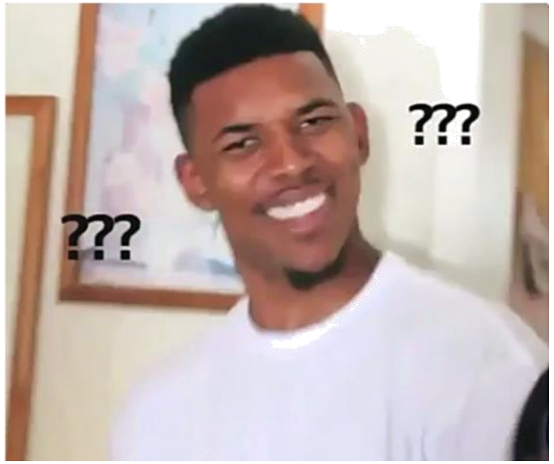
  Apply calibrations(校準)

Measurement error mitigation

The ideal is very simple…

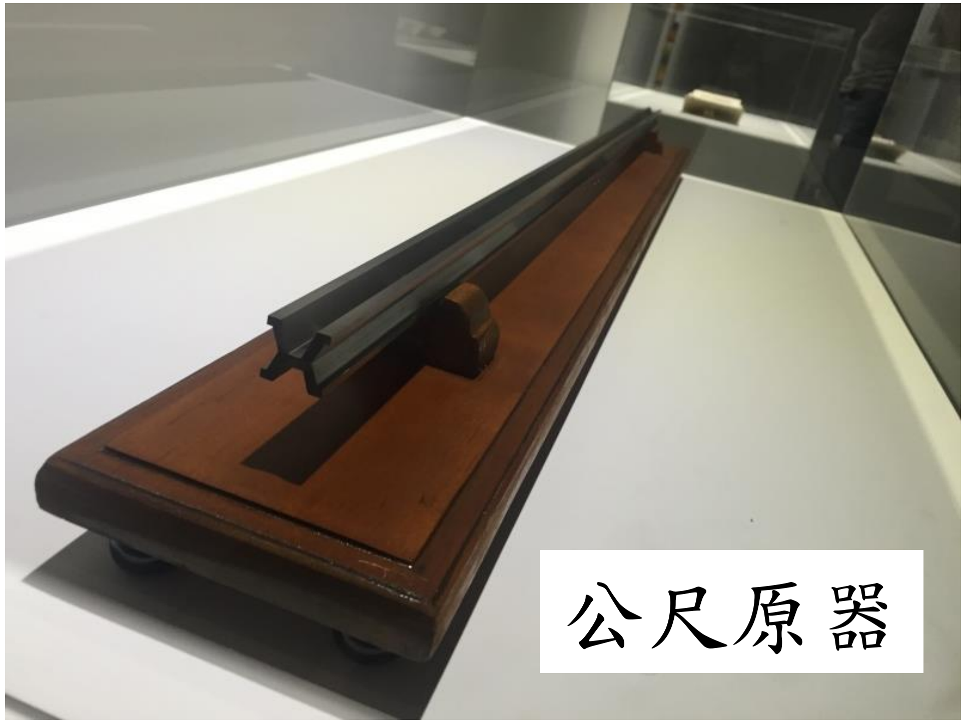
Suppose we have a ruler, but the ruler is not calibrated.
The ruler is our tool to perform measurements.

What can we do?



Measurement error mitigation

What if we have a “reliable” benchmark(基準)?



Measurement error mitigation

By measuring the benchmark, we can obtain the deviation of the ruler.

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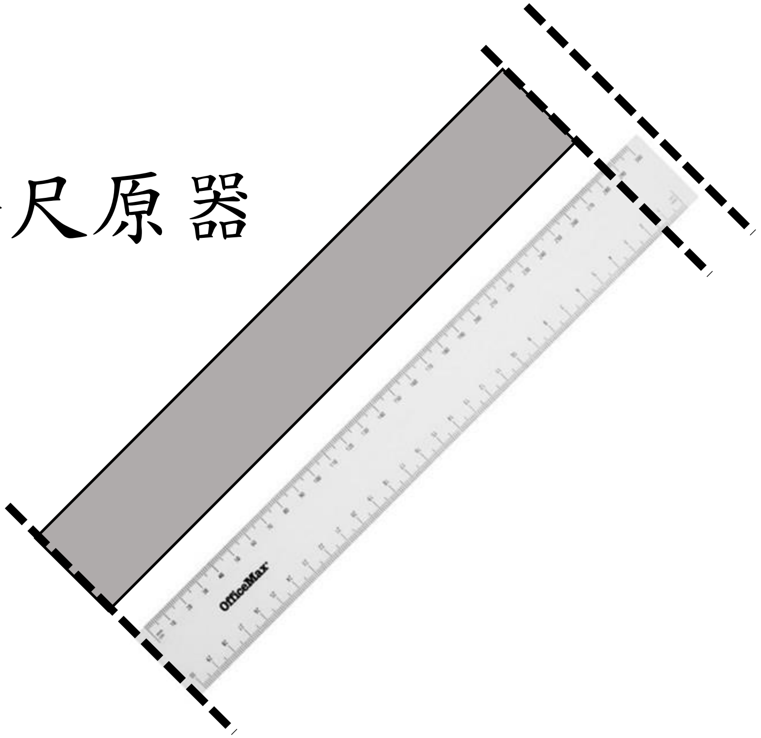
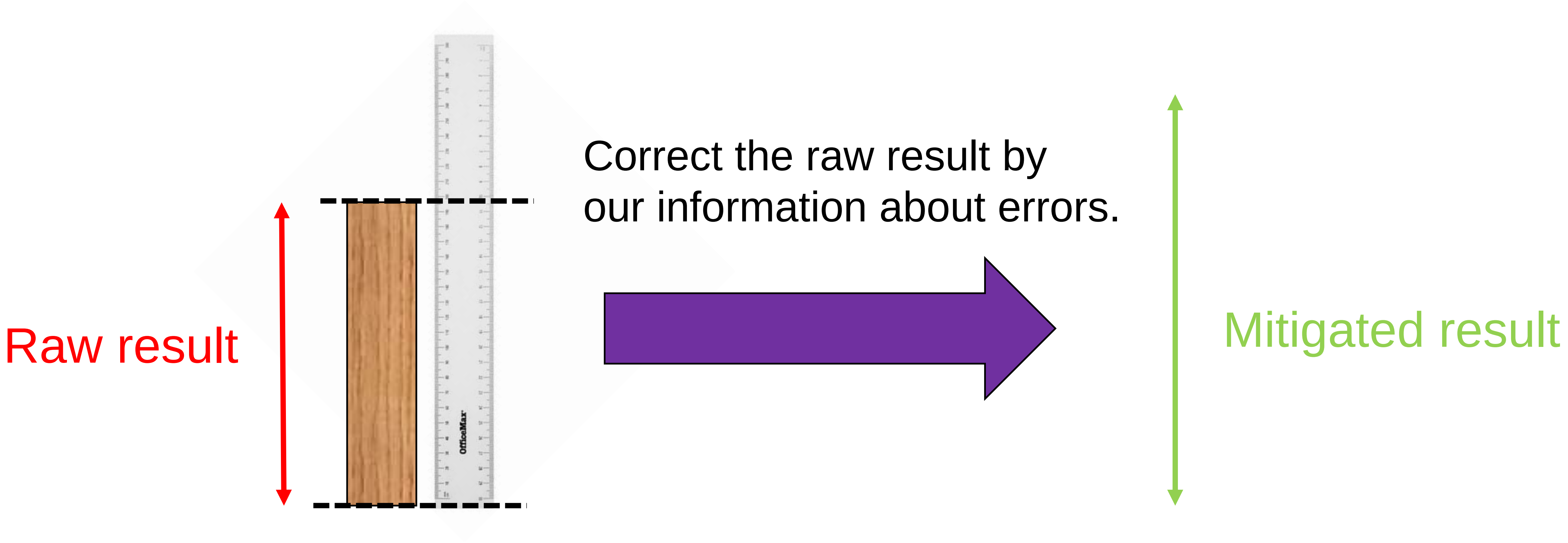


If we further know the deviation of ruler is constant (broken in half), or linear (thermal expansion), we can know the ***factor*** of error!

Measurement error mitigation

Now, we are able to use the ruler confidently!



Measurement error mitigation

Qubit measurements are imperfect, but sometimes we can mitigate the resulting errors

- In experiments where only a single measurement is performed, we can't correct for measurement errors since measurement affects the state of the qubit.
- In experiments where the goal is to compute an expectation value or average probability over many shots, it is possible to approximately correct for the effects of measurement errors by performing appropriate calibration experiments.

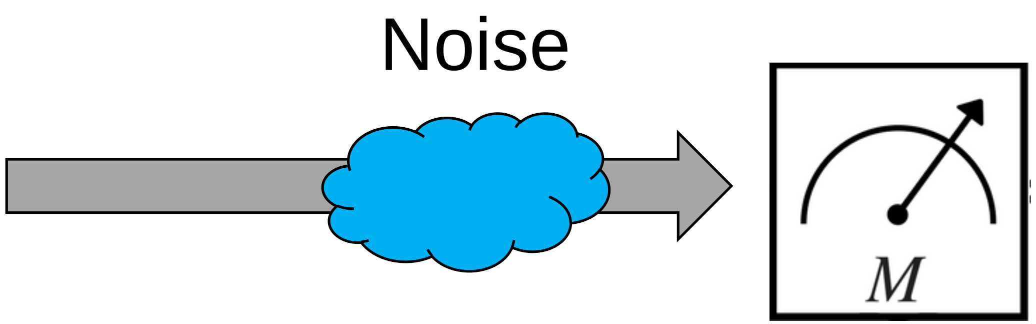
Calibration matrix

The assumption of the error mitigation: 公尺原器

We can prepare each of the basis states with very low error.

Given this assumption, in separate experiments we can prepare **one** of the 2^n states and then measure the outputs in all 2^n states.

Prepare the basis state $\begin{pmatrix} 0 \\ \vdots \\ 0 \\ 1 \\ 0 \\ \vdots \\ 0 \end{pmatrix}$



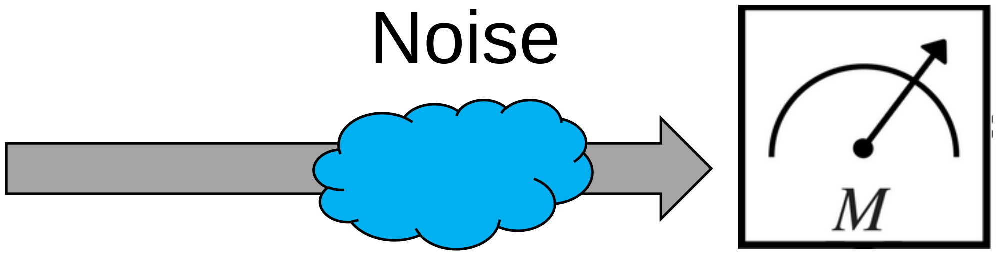
$\begin{pmatrix} 0.02 \\ \vdots \\ 0.01 \\ 0.9 \\ 0 \\ \vdots \\ 0.001 \end{pmatrix}$

Calibration matrix

Assumption on error model

Normalizing these outputs and making each set of output probabilities for a given prepared state the columns of a matrix we obtain the matrix $\boldsymbol{A}$ which translates the ideal probability distribution of the state ρ (P_ρ) into the experimental probability distribution $\widetilde{\mathrm{P}}_\rho$.

i_{th} basis $\begin{pmatrix} 0 \\ \vdots \\ 0 \\ 1 \\ 0 \\ \vdots \\ 0 \end{pmatrix}$

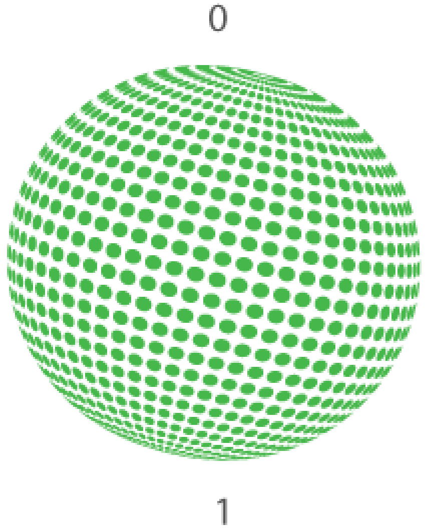


Experiment result

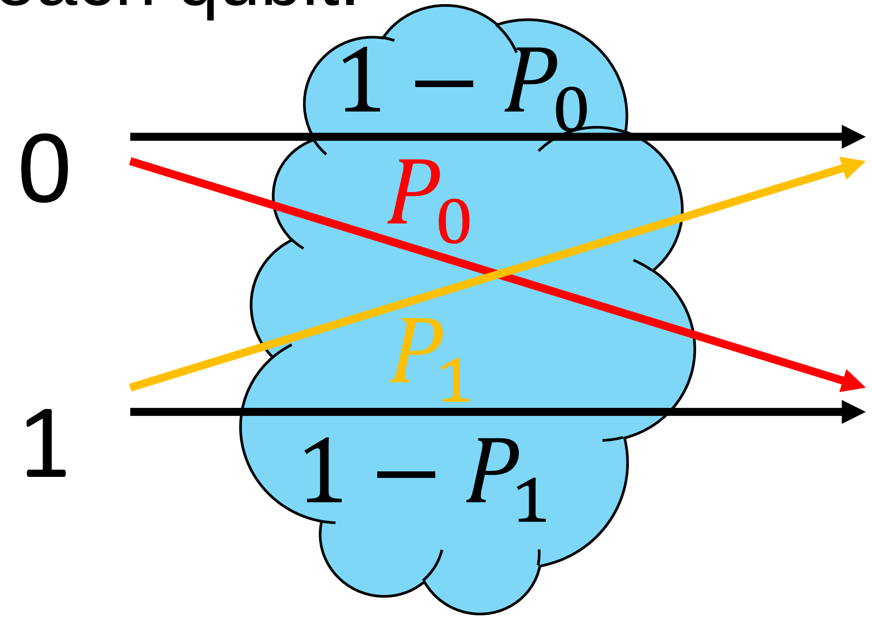
$\begin{pmatrix} 0.02 \\ \vdots \\ 0.01 \\ 0.9 \\ 0 \\ \vdots \\ 0.001 \end{pmatrix}$ i_{th} column of A

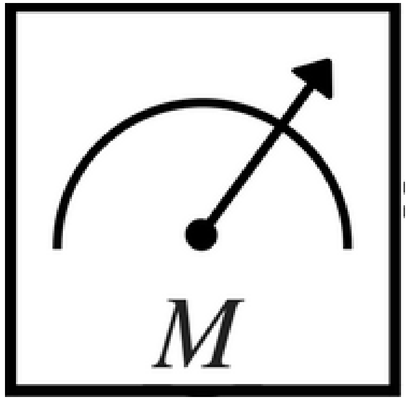
Calibration matrix

An example for error model (readout_noise in Qiskit):
In the measurement **distribution** error can by characterized by a **binary channel** for each qubit.



i_{th} $qubit$





E_i: $binary\ channel$

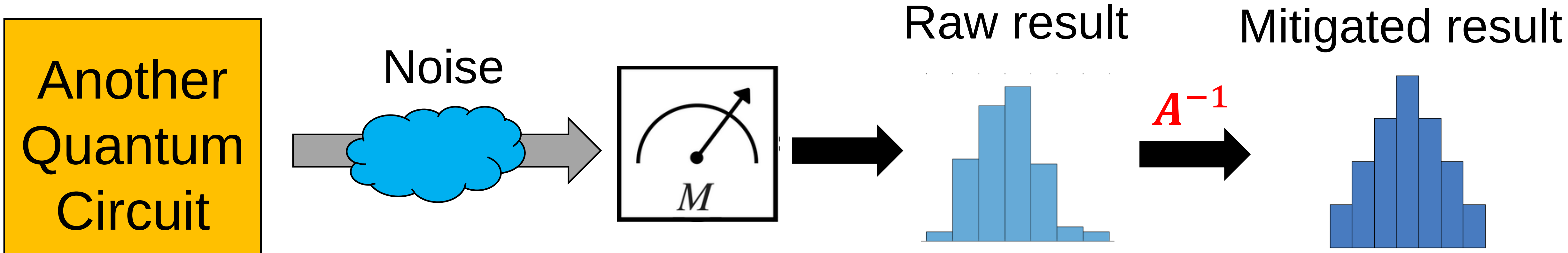
Calibration matrix

If we have the calibration matrix $\boldsymbol{A}$ which gives the transformation between the distributions,

$$\widetilde{P_\rho} = \boldsymbol{A} \cdot P_\rho$$

then to work back to P_ρ we just need to invert $\boldsymbol{A}$,

$$P_\rho = \boldsymbol{A}^{-1} \cdot \widetilde{P_\rho}$$



Calibration matrix

If you run the code several times, you will likely see some **negative** counts. This is because there is some statistical noise in the calibration matrix which means that the corrected results will be unphysical. To correct for this we can find the P_ρ which is closest to reproducing the measured output,

$$\min_{P_\rho} \| \widetilde{\mathrm{P}_\rho} - \boldsymbol{A} \cdot \mathrm{P}_\rho \|$$

but where all elements of P are non-zero.

Thanks for your attention!

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