# Enhancing the efficiency of nuclear equipment adjustments: Statistical techniques for minimal datasets

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At RIKEN RIBF, research activities are conducted using various secondary beams with significant changes in the setup for each experiment. While this style enables diverse experimental studies, it has the disadvantage of a significant overhead for each experiment. Although the beam time for each experimental program is typically about one week, it often requires more than a day for the startup of large-scale devices such as the SAMURAI spectrometer.[1)] The startup procedure must be performed efficiently to maximize the use of valuable beam time.

A multi-wire drift chamber (MWDC) is a gas detector used to obtain trajectory information for high-intensity secondary beams provided at RIBF. Because the signal amplification is achieved through the electron avalanche inside the detector, the optimal voltage to be applied is very sensitive to the energy, charge, and intensity of the beam. In the past, detection efficiency measurements have been made for typically more than 10 different voltages for the optimization. In this report, we propose a method to achieve sufficient optimization with as few as two measurements.

From the experience accumulated over the past decade of irradiating various secondary beams to the SAMURAI spectrometer, empirical measurement shows that the detection efficiencies of Walenta-type MWDCs (BDCs, FDC1) and the MWDC with a hexagonal cell structure (FDC2) can be fitted with the logistic and log-logistic functions, respectively. Figure 1 show the efficiency curves for BDC1 and FDC2 measured for $^{10}$Be at 230 MeV/nucleon in April 2024.[2)]

The logistic function shown in Eq. (1) is mathematically equivalent to the linear logit function shown in Eq. (2). This transformation leads us to the problem of linear regression, which can achieve small errors even with a small number of samples. The following procedure was used to attempt to estimate the optimum voltage at which the detection efficiency is 99%.

$$\epsilon = \frac{1}{1 + e^{-(\beta_0 + \beta_1 V)}} \tag{1}$$

$$\log\left(\frac{\epsilon}{1-\epsilon}\right) = \beta_0 + \beta_1 V \tag{2}$$

**Step 1** Take one measurement at $V_1$ under the assumption that the voltage with an efficiency of 50% is known in advance with an accuracy of 50 V.[a)]

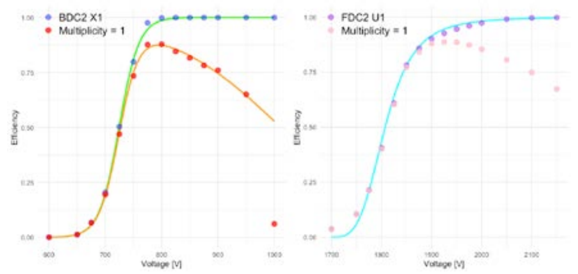


Fig. 1. Left: BDC efficiency fitted using a logistic function (green curve) and BDC multiplicity fitted using the product of two separate logistic functions (orange curve); Right: FDC2 efficiency fitted using a log-logistic function (cyan curve).

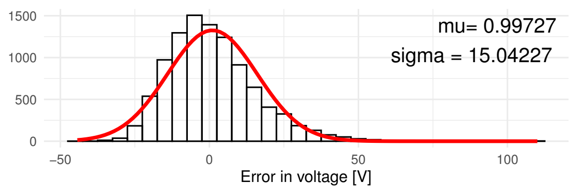


Fig. 2. Errors of the voltage at 99% efficiency.

**Step 2** Take the other measurement at $V_2 = V_1 \pm 25$ [V], depending whether the detection efficiency $\epsilon(V_1)$ is smaller/larger than 50%.

**Step 3** Estimate $\beta_0$ and $\beta_1$ from Eq. (2) using the measured efficiency at $V_1$ and $V_2$. Based on the estimated values of $\hat{\beta}_0$ and $\hat{\beta}_1$, predict the voltage at 99% efficiency.

To mimic actual experimental conditions, we estimated the detection efficiency at each $V_1$ and $V_2$ by adding fluctuations to the logistic function shown in the left panel of Fig. 1. The error distribution of this procedure is shown in Fig. 2. Measurements of at most two points enabled us to estimate the optimal voltage with an accuracy of typically 15 V. This is sufficient accuracy for practical use, and voltage optimization can be completed by simply adding a few more measurements around this point. The method is applicable to different ions, and the results not only enable more efficient startup, but also show the potential to change the previous scenario, which required highly-skilled experts.

References
1) T. Kobayashi *et al.*, Nucl. Instrum. Methods Phys. Res. B **317**, 294 (2013).
2) H. Wang *et al.*, in this report.

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a) The voltage corresponding to 50% efficiency has been previously determined through measurements conducted with diverse beams because the MWDC utilized in SAMURAI has been operated with various beams not only at RIBF but also at HIMAC, providing empirical knowledge on the gas gain as a function of applied voltage.

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