CyTOF XT

Advancements in Data Acquisition and Processing

Introduction

CyTOF technology. Mass cytometry by time-of-flight, the basis of CyTOF instruments, is a high-parameter cell-profiling technology that enables simultaneous detection of over 50 cellular targets in a single sample tube, making it a valuable addition to cytometry core facilities, service laboratories, and contract resource organizations. Powerful CyTOF technology has been adopted for use by key clinical research consortia[1,2,3] and in scores of **National Clinical Trials**.

NeXT-generation instrument. Standard BioTools™ has launched its newest-generation flagship mass cytometer, CyTOF XT™, with sample acquisition automation that advances planning and execution of multitarget studies to the next level.

CyTOF XT shares the same reliable, powerful features and level of performance with its predecessor, Helios™, but with several novel improvements to the acquisition hardware and software, including:

- An innovative Autosampler module for increased productivity and sample throughput.
- Enhanced system monitoring and clog-removing algorithms for worry-free unattended acquisitions.
- Additional functional changes that facilitate extended acquisitions, update tuning routines, provide additional quality control metrics, improve data management, and more.

For more information on key features of the new instrument, refer to the CyTOF XT: The Next Generation of Mass Cytometry Application Note (FLDM-00462).

Objectives

This technical note demonstrates in greater detail the significant CyTOF XT innovations that positively impact instrument operation, data quality, and the overall user experience. Along with the new CyTOF Software v8.0, these advancements offer:

- Faster **Tuning** – an instrument calibration for daily use.
- Sustained optimal level of detector sensitivity over extended runs by **Auto Detector Voltage (DV) Optimization.**
- Streamlined and on-the-fly **Data Processing** of event identification and reported event parameters.

Together, these CyTOF XT features greatly reduce the expertise needed to acquire high-parameter cytometry data.

This technical note consists of three sections, which are intended to help new and experienced users:

- Understand updates to the tuning protocol and the contribution of each calibration parameter to faster and more robust tuning.
- Appreciate the advantages of automated monitoring and adjustment of detector voltage over long runs.
- Learn about advancements in the calculation of Gaussian parameters and how a cell develops into an event – from a bundle of pushes to cleaned data (single-cell events).

Streamlined Instrument Tuning

Instrument calibration (also known as tuning) is a brief but essential component of the daily mass cytometry workflow. Because a mass cytometer is a sensitive instrument capable of detecting single ions, performing a daily calibration ensures that measured values correspond to tuning standards of known accuracy. For CyTOF XT, tuning is designed to maximize signal detection from cells by optimizing the front-end alignment and other key instrument parameters.

Built on the foundation of previous generations of mass cytometers, CyTOF XT uses a new and improved tuning algorithm that provides a fast, stress-free, and easy-to-troubleshoot instrument calibration experience.

Along with the updated tuning algorithm, CyTOF XT uses EQ™ Six Element Calibration Beads (EQ6 beads, Cat. No. 201245) for tuning instead of Tuning Solution (Cat. No. 201072) used with previous generations of mass cytometers.

The new EQ6 beads simplify CyTOF XT operation and provide several additional benefits that result in more accurate, more robust, and faster everyday tuning (Table 1). Moreover, the new Autosampler module design transforms this process into a single-click routine.

Table 1. Features and benefits of the major improvements to CyTOF XT instrument tuning

Major Improvements	Features	Benefits
Replacement of Tuning Solution with new EQ6 beads	EQ6 beads are placed into a dedicated tube of the CyTOF XT Autosampler carousel for automated instrument tuning. By combining tuning and bead sensitivity tests, EQ6 beads facilitate instrument tuning and provide quality control (QC) measurements.	• Faster tuning routine • Bead data is collected in a separate FCS file for QC and troubleshooting purposes. • Fully automated tuning protocol. No need to switch tuning reagents (water, Tuning Solution, and Cell Acquisition Solution). • Longer system component lifetime through the elimination of acid-based instrument maintenance washes • Reduced data variability because the same beads are used for tuning and as an internal standard
Tuning is based on the detection of transient events, not continuous solution flow.	Bead transient events are quantified during tuning and sample acquisition, thus providing a standard in both modes.	• Faster tuning routine. No need to wait for full stabilization of bead signals in the solution since all beads carry the same quantity of metal isotopes and generate similar signals.
Broader mass response curve	Elements on EQ6 beads cover a broader range of masses, from 89 to 209 amu, while EQ4 beads cover 140–175 amu.	• More accurate signal normalization scaling factor for masses in the 89–140 and 175–209 amu ranges. This is especially important for reagents labeled with Y, Pd, Cd, and Bi. • Reduced instrument-to-instrument variability and increased consistency of tuning and normalization results

Changes in calibration parameters

Users now have full visibility of each calibration parameter in CyTOF Software (Mass tuning, XY alignment, Detector Voltage, Current, Nebulizer Gas, and Makeup Gas) with QC metrics that help pinpoint potential tuning problems.

Tuning of each parameter is optimized for faster completion and more consistency across instruments and days. Key changes to the tuning workflow:

- Optimal XY alignment is found more quickly using a shorter range around current XY values instead of scanning the entire range.
- The values of dual coefficient are used to automatically optimize the detector voltage (DV) during tuning. Also known as Auto DV optimization, this process is implemented to obtain the same detector gain for each sample, thus sustaining the same level of instrument sensitivity.
- Nebulizer gas calibration uses a new pressure sensor that minimizes nebulizer-to-nebulizer differences and optimizes nebulizer gas flow values.
- An improved algorithm for optimal makeup gas (MUG) flow scans for intensity and oxides together, shortening the waiting time.
- The QC Report now contains all tuning calibration metrics [including bead sensitivities, coefficients of variation (CVs), relative standard deviations (RSDs), and oxide ratios] and background signal measurements for common environmental contaminants.

A full summary of tuning advancements is provided in Table 2.

Section summary

As outlined in Table 1 and Table 2, the updated and streamlined tuning routine provides significant improvements to the user experience while ensuring a reliable and smooth everyday workflow. To learn more about Auto DV and how it helps sustain the same level of signal intensity during long acquisitions, continue to the next section.



Table 2. Features and benefits of the major improvements to each tuning calibration parameter (listed in order of appearance in the QC report)

Calibration Parameter	Features	Benefits
Mass tuning is defined using EQ6 beads.	• The time-of-flight (TOF) of all masses is calculated based on the argon dimer and EQ6 bead metal isotopes in the time-of-flight window.	• EQ6 beads are used for tuning, so additional Tuning Solution is not required.
Faster **XY alignment**	• Optimum value for XY alignment is found in a shorter range around current XY values. In rare cases, if optimal XY is not found in a shorter range, the system scans a full range automatically during tuning.	• Faster instrument tuning due to efficient determination of optimal XY alignment
Detector Voltage is not limited to tuning only.	• Detector voltage calibration and on-the-fly Auto DV use xenon (Xe) signal and not cesium (Cs) signal as the reference.	• Highly stable instrument sensitivity by sustaining the same detector gain for each sample loop
Current calibration is defined using EQ6 beads.	• Current is defined based on signal of transient events (EQ6 beads) instead of Tuning Solution.	• EQ6 beads are used for current calibration, so additional Tuning Solution is not required
New pressure sensor improves New **Nebulizer Gas** flow calibration.	• CyTOF XT has a new nebulizer gas pressure sensor that reduces signal variability during gas flow calibration.	• Pressure readings provide robust and consistent calibration values regardless of nebulizer-to-nebulizer differences.
Accelerated search of optimal **Makeup Gas (MUG)** setting	• The optimal MUG value is found in a shorter range, and the new algorithm stops searching when the signal intensity decreases or if oxides exceed set limits. • The QC Oxide Ratio is calculated based on the 140Ce signal present in EQ6 beads and not the 139La signal in Tuning Solution.	• Faster instrument tuning due to efficient determination of optimal MUG parameters • EQ6 beads are used for calibration, so a separate bead calibration test is no longer required.
QC Report is accessible from the Tuning window.	• Bead sensitivities, CVs, RSDs, and oxide ratios are now shown in the QC Report. • Background signals from common environmental contaminants are also shown in the QC Report.	• Generation of a comprehensive QC report that includes bead sensitivity and background checks
Manual Tuning is a new available option.	• Experienced users may choose which parameters to manually tune.	• Users have control over which parameter to tune and troubleshoot.

Auto DV Maintains Signal Intensities over Long Runs

CyTOF XT is designed to maximize signal detection for long acquisitions by implementing a new Auto DV optimization feature that monitors and adjusts detector voltage during sample runs to sustain the same level of signal intensity for up to 23 hr.

Demonstration of Auto DV

A test was designed to show the effectiveness of the Auto DV optimization algorithm in a 23 hr run. Leukocytes from lysed whole blood were stained in bulk with a custom marker panel and split into multiple replicates. Nine replicates were loaded into the carousel and set for an unattended run with Auto DV optimization turned on (default setting).

Sample-to-sample test results

23 hr of unnormalized replicate-to-replicate data is presented in Figure 1. Signal intensity peaks of markers for all samples are virtually indistinguishable. Specifically, the maximum difference of median signal intensities was 3.3% of dual counts between the first and last tubes. The stability of signal distribution between the replicates was consistent with maximum CV of 1.49% in CD45 channel.

Furthermore, each loop of these replicates within the 23 hr period was analyzed for marker intensity readings and plotted as a dot plot. Before proceeding to the loop-to-loop results it is important to understand the basic concept of sample acquisition in discrete portions or loops.

The concept of loop acquisition

The innovative design of the CyTOF XT Autosampler module enables the acquisition of 13 sample tubes in a carousel arrangement, where samples are transferred in a 250 µL sample loop before continuing to the nebulizer and spray chamber. Instead of a continuous sample flow, the sample loop delivers a fixed 250 µL of sample volume per loop.

Each loop is therefore both a sample fluidics component (Figure 2A) and a discrete 250 µL portion of a sample collected as data in an FCS file (Figure 2B).

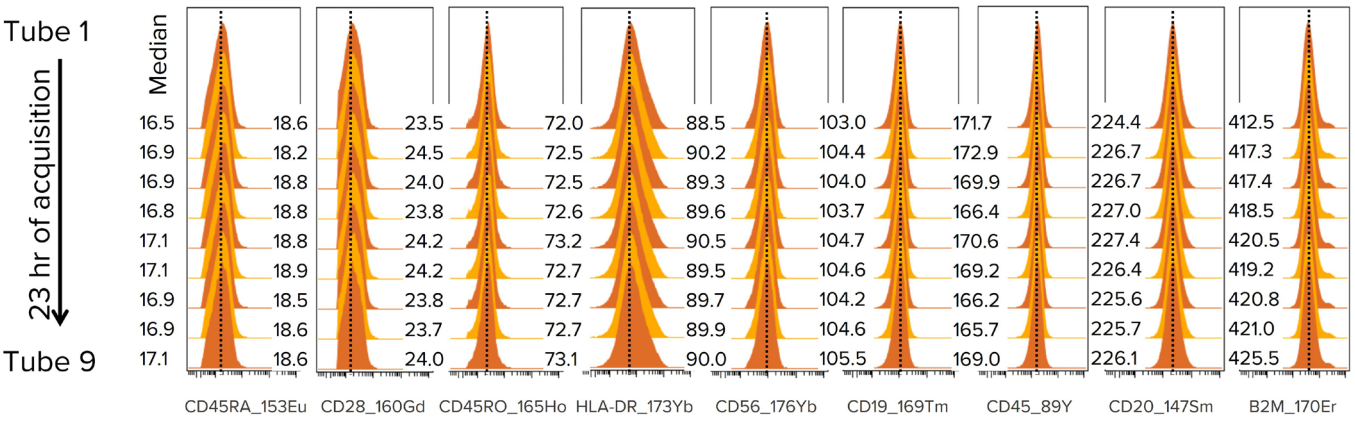


Figure 1. Marker signal intensity of unnormalized data for 9 replicates over a 23 hr run. Markers are shown in the order of increasing intensity, from dim to bright.

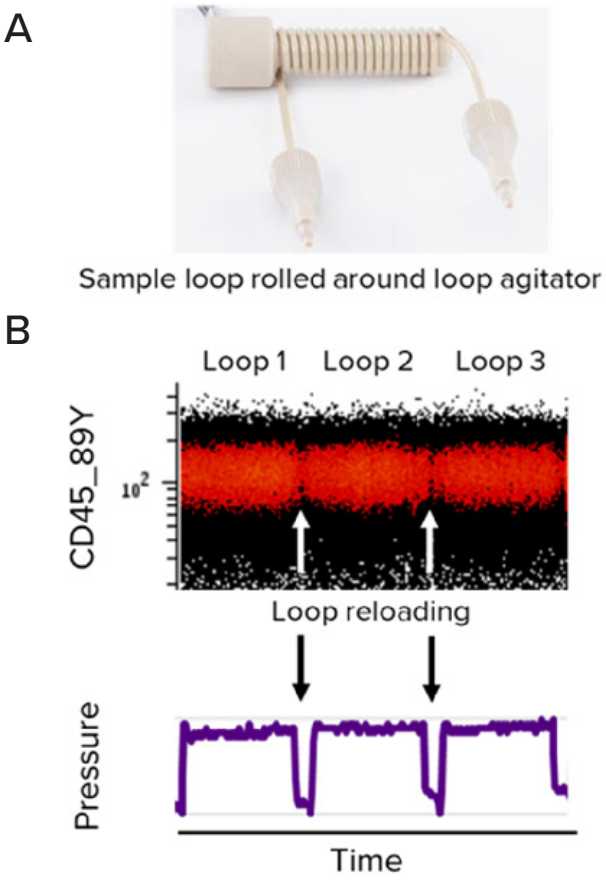


Figure 2. A) Sample loop and sample loop agitator are a part of CyTOF XT fluidics that delivers 250 µL of the sample at a time. **B)** Dot plot of CD45 marker intensity over time, where visible breaks in event density correspond to pressure changes due to loop reloading by the syringe pump.

Impact on data quality

There is a brief pause in cell acquisition during loop reloading (Figure 2B), which does not affect data quality during continuous sample introduction.

Loop-to-loop test results

Auto DV optimization occurs before each loop (or 250 µL of sample) is injected to the spray chamber, ensuring consistent instrument sensitivity levels for every loop.

To demonstrate this consistency in signal intensity over time, 132 loops of data from Figure 1 were analyzed and graphed in Figure 3 for EQ6 bead markers and cellular markers over 23 hr of unsupervised acquisition, equaling approximately 33 mL of sample.

Maximum signal intensity fluctuation in the entire dual count range was 1.22% and 2.47% (CV) for bead markers (Figure 3A) and live cell markers (Figure 3B), respectively, indicating highly consistent intrasample (loop-to-loop) signal readings.

Section summary

Sample-to-sample and loop-to-loop test results demonstrate that the new Auto DV optimization feature is able to sustain a constant level of sensitivity over time by adjusting the detector voltage (if needed) before each sample loop, and that small fluctuations in single loops do not affect the average intensity of markers detected within the sample.

Along with Autosampler module features that minimize hands-on time (automatic handling of samples and solutions, and tuning, unclogging, and shutdown workflows, among others), Auto DV optimization enables worry-free unattended acquisitions on CyTOF XT. To learn more about how CyTOF XT facilitates productivity, refer to the CyTOF XT: The Next Generation of Mass Cytometry Application Note (FLDM-00462).

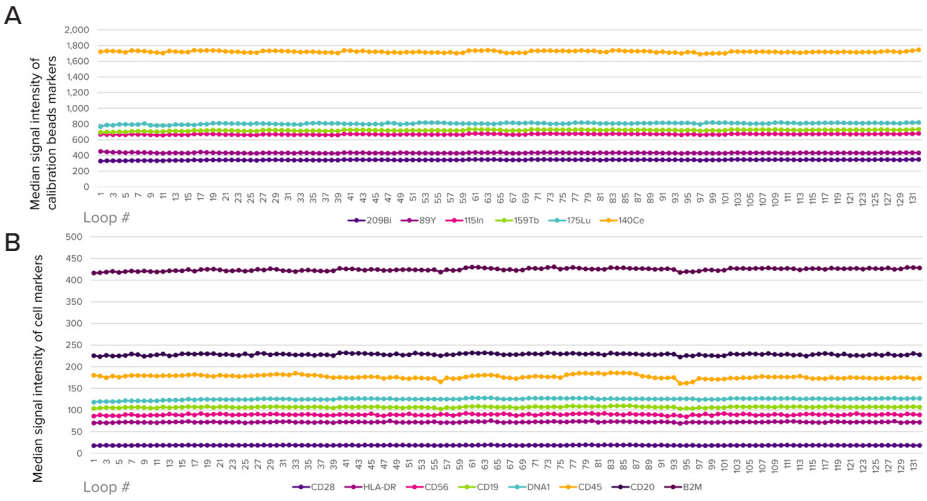


Figure 3. Unnormalized intensity values of **A)** bead markers and **B)** live cell markers over 132 loops during 23 hr of unsupervised acquisition. Stable level of sensitivity across all markers, from low to high expression, is demonstrated. This figure represents the same samples shown in Figure 1. Values for CD45RA and CD45RO are not shown to avoid overlapping results with CD28.

Advancements in Event Identification

The following section explains how advancements in event identification on CyTOF XT enable:

- Generation of transient curves from the integration of cell-derived ion signals.
- Improved identification of Gaussian fitting parameters from transient curves.

Important Terminology

It is important to clarify the terminology used before proceeding to the next sections.

- In mass cytometry by time-of-flight (TOF), the basis of CyTOF systems, a cell becomes an ion cloud in hot plasma. Before reaching the detector, the ion cloud is stretched when passing through the ion optics and sampled into multiple TOF segments of the same time duration also known as **pushes**.
- The analog ion signal is digitized and is presented as dual counts in the software. One **dual count** means that one ion has been detected.
- **Marker signal intensity** is an abstract term that means the strength of the signal. Marker signal intensity is presented in dual counts. For simplicity, the terms signal intensity and dual counts are used interchangeably.
- Hereafter, all curves represent dual count signal and are called **transient curves** when plotted against time (Figure 5B). The term transient describes the evolution of a signal above the threshold level during multiple pushes. One transient corresponds to one event, and these terms are used interchangeably.

From Ions to Event Identification

Real-time event visualization in CyTOF Software v8.0

CyTOF XT analyzes over 75,000 pushes per second that are visualized in CyTOF Software v8.0 or later in real time in a rain plot or storm plot (up to 5,000 pushes). Both plots provide the same information. However, the axes are flipped on the storm plot (for more information on storm plots, see the CyTOF Software v8.0 Help available in the CyTOF Software). An example rain plot is shown in Figures 4A and 4B.

Rain plots are commonly available in all generations of mass cytometers. Ions that are separated by mass in TOF systems are visible in the rain plot as lines. Each line represents a collection of ion signals of the same mass (Figure 4A). An increased detection of ion signals results in a darker intensity line at a given push, and a bundle of lines can appear as a high density bar.

The Event pane in the rain plot (Figure 4B) digitally represents the state of the summed signal as being either above or below a preset threshold. The length of an uninterrupted streak above the threshold in this graph corresponds to the event length reported by the software. The event length is measured in pushes. In the example shown in Figure 4B, the length of a detected doublet is greater than the length of a detected singlet.

Transient curve visualization

CyTOF Software v8.0 registers an event (or transient) when the sum of the channel intensities selected for event detection surpasses a preset threshold (Figure 4B). This is a new feature of CyTOF Software v8.0 for visualizing intensities of detected events in real time in rain plots or storm plots.

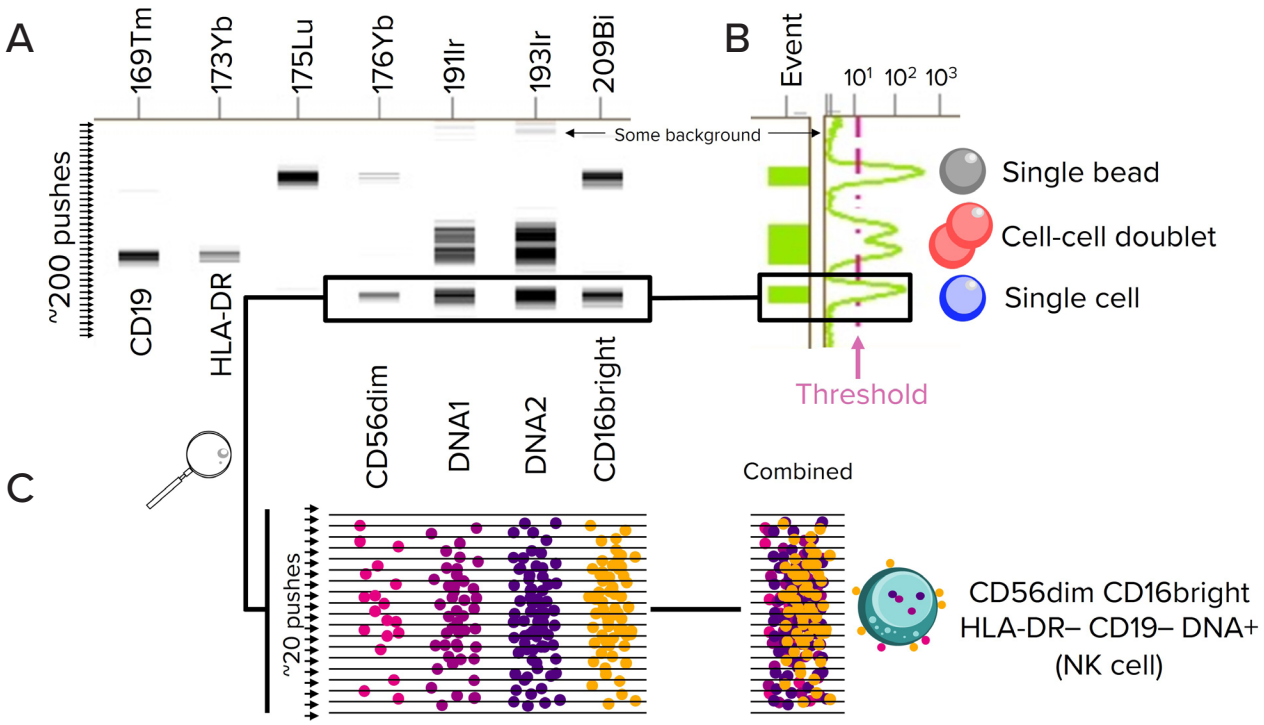


Figure 4. A) Rain plot from CyTOF Software v8.0 showing 3 distinct event types: single bead, cell-cell doublet, and single cell. Lines represent positive metal ions of a corresponding isotope with cumulative signal intensity bars. **B)** Event pane and transient curve visualization of summed signal intensities in detectable channels for each event type. **C)** Enlarged sketch of positive ion bundles likely identifiable as a peripheral blood natural killer (NK) cell (CD56dim CD16bright CD19– HLA-DR– DNA+ event).

The 3 main event types (single-bead, single-cell, and cell-cell doublet events) generate different transient curves, as shown in Figure 4B. In addition, the event length of a single bead is the same as that of a single cell, but their peak heights (amplitudes) are different. In this example, there is also a small amount of background noise in DNA channels (light gray lines preceding the bead event) that is below the detection level and therefore not counted as an event.

Figure 4C depicts an enlarged sketch of each positive ion bundle. It is possible to identify cell types on the fly by determining the combination of metals and their densities in the rain plot or storm plot. The selected frame shows that the event is positive for CD56, CD16, and DNA channels and negative for EQ6 bead markers and antigen-presenting cell (APC) markers (CD19 and HLA-DR). Density differences in the marker channels indicate that the event has dim CD56 expression and bright CD16 expression. The single peak of the transient curve in Figure 4B identifies the positive ion bundle as a single event. Collectively, the information distilled from these plots signifies that this event is not a bead, but a single cell that is likely a peripheral blood natural killer (NK) cell (CD56dim CD16bright CD19– HLA-DR– DNA+ event).

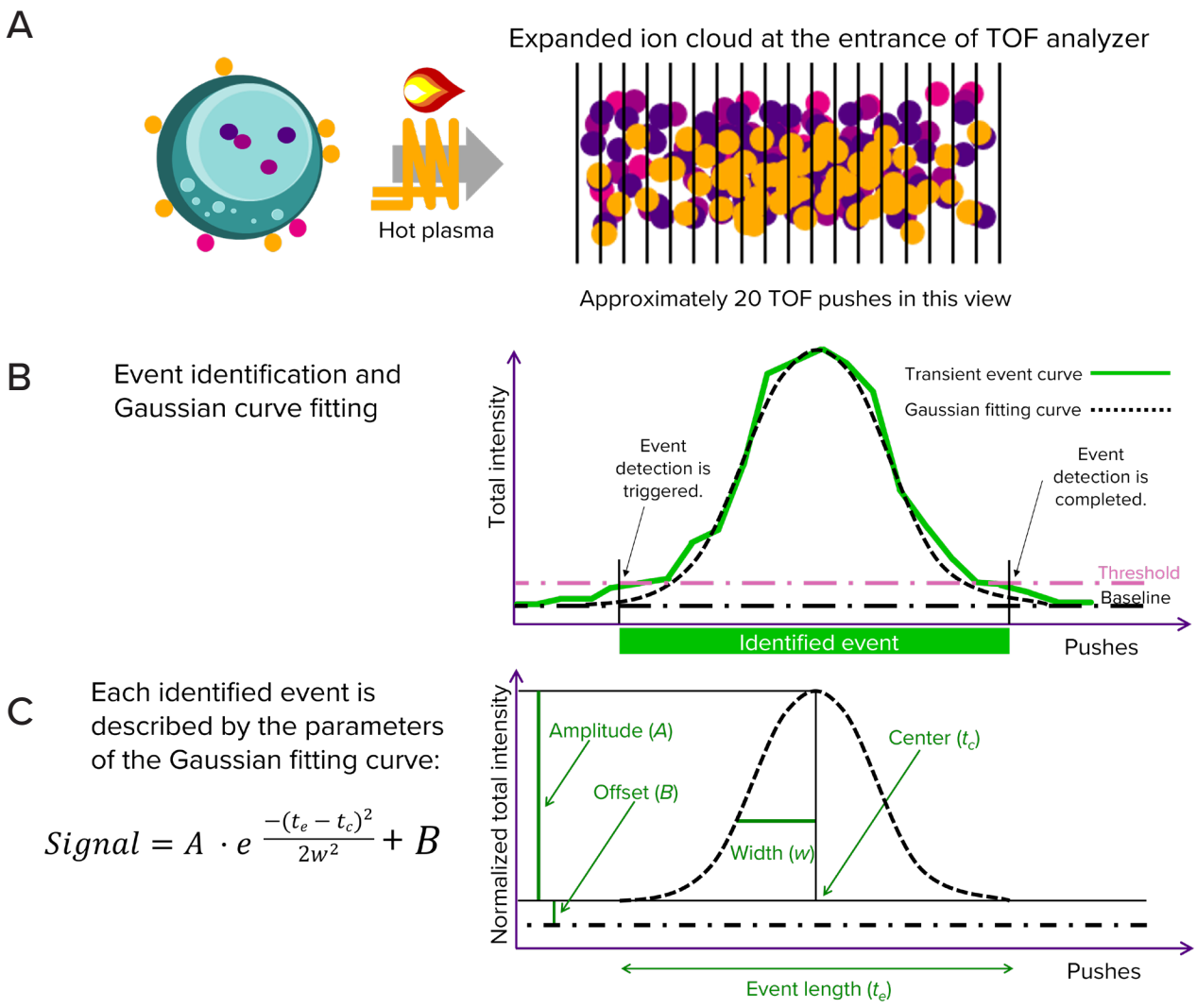


Figure 5. A) Continued from Figure 4, depiction of the expansion and sampling of the cell-derived ion cloud by the push-out plate, before the mass-resolved ion packets arrive at the TOF analyzer. **B)** Illustration of a single-cell transient curve as a sequence of the total ion current points of all selected masses registered by the detector. Event detection is triggered when the intensity signal intersects with the threshold and is completed when the intensity dips below the threshold. **C)** Parameters and formula of a normal distribution that define the Gaussian fitting curve.

Gaussian Fitting and Data Cleanup Strategy

Gaussian discrimination parameters (such as Residual, Offset, Center, Width, and Amplitude) are descriptive parameters included in mass cytometry FCS files to assist users in identifying single-cell events.

This section:

- Explains the origin of Gaussian parameters in mass cytometry output files.
- Describes an improved calculation of these parameters and a strategy for using them to obtain ready-to-analyze data.
- Provides optimal parameter ranges for single-cell events.
- Illustrates how to identify different types of events including singlets, doublets (or triplets, quadruplets, etc.), and debris by using an improved cleanup method with these parameters.

From analog to digital

In CyTOF systems, a cell is ionized in hot argon plasma and becomes a cloud of positively charged ions. This ion cloud expands while traveling toward the TOF analyzer and is sampled into multiple consecutive pushes. Mass-resolved ion packets in each push are registered by the detector. The sum of all mass-specific single push signals defines total ion current for each push.

As a cell becomes an expanded ionized cloud in the plasma, it carries the most metal tags in its largest circumference and fewer tags on the ends (Figure 5A). As a result, the ion current curve for a single-cell ion cloud is bell-shaped and can be well-described by the Gaussian function (Figure 5B).

Event types differ by their transients: high-intensity and low-intensity, singlet and doublet, and short-length and long-length transients. Gaussian fitting collects them under the same denominator and assigns parameters to each detected event (Figure 5C). In other words, Gaussian fitting is a way to normalize a variable nature of different transient curves.

These parameters characterize the events and can be used in a manual gating cleanup strategy to select the singlet events of cells with the best alignment of both intensity and fitting curves.

Gaussian parameters of a common singlet and a common doublet

The CyTOF Software v8.0 algorithm applies the best fit to the transient event curve. Multiple consecutive transient bell-shaped event curves together cannot be well-described by one Gaussian fitting curve. Therefore, the difference between the values of the reported Gaussian parameters of singlets and doublets (Figures 6B and 6C) can be distinguished in the biaxial plots (Figure 6A).

There are 2 groups of Gaussian parameters reported as separate channels in the FCS file:

- Signal strength parameters: Offset, Residual, and Amplitude
- Time parameters: Center, Width, and Event Lengths

The Offset and Residual, and Center and Width parameters are calculated and appear differently in CyTOF Software v8.0 than in the previous versions of CyTOF Software. Unlike earlier software versions, these parameters are normalized by the Amplitude (Offset and Residual) and Event Length (Center and Width) parameters for more accurate identification of singlet events (Figure 6A).

Offset and Residual parameters have similar calculations and are simplified equivalents of the mean and standard deviation (SD), respectively. These 2 signal strength parameters are normalized by Amplitude and show how far the alignment of a Gaussian fitting curve is from the transient event curve (Figures 6B and 6C). The greater the Offset and Residual value, the larger the difference (or delta, Δ). For example, Offset and Residual values for doublets are always higher than singlets (Figure 6A) because there is misalignment between the Gaussian fitting and transient event curves.

When Offset and Residual values are plotted against time during a cleanup, the anticipated population and the events below it should be selected for further analysis. Offset and Residual of an ideal singlet transient should equal 0 (zero).

Offset and Residual are very effective signal strength parameters that can be used to identify most singlet events. Likewise, the Center and Width time parameters can be used in manual gating to exclude non-singlet events, including debris.

The Center parameter expresses the relationship between the length of an event and the center position of its Gaussian fit curve (Figures 6B and 6C). The reported Center parameter of an ideal singlet is always in the middle of the bell curve and is equal to approximately half the Event Length. The reported Center parameter of a perfect singlet is 0.5 multiplied by the normalization factor of 10^3. Because most singlets are not naturally perfect, the Center of a common singlet population is typically a narrow band located between 300 and 500 (Time parameters panel in Figure 6A). Also shown in the Figure 6A example, the median Center of the singlet population equals 420.

Similar to Center, the Width parameter equals the Gaussian width of the fitting curve with a multiplier of 10^3 (Figures 6B and 6C) and is typically approximately 4–6X less than the Event Length. Therefore, the Width value is expected to be a band located between 100 and 250.

Essential parameters for a cleanup strategy

The Gaussian parameters of Offset and Residual, and Center and Width, are calculated using Event Length and Amplitude. Consequently, only these 4 parameters are necessary for accurate data cleanup. Correct application of these 4 Gaussian parameters in gating is a powerful way to exclude approximately 99.0–99.9% of all non-singlet non-cell events from further downstream marker analysis. Using all 4 parameters ensures that undesirable events that may have slipped through single gates due to inaccuracies in manual gate placement are eventually removed.

Recommended cleanup strategy

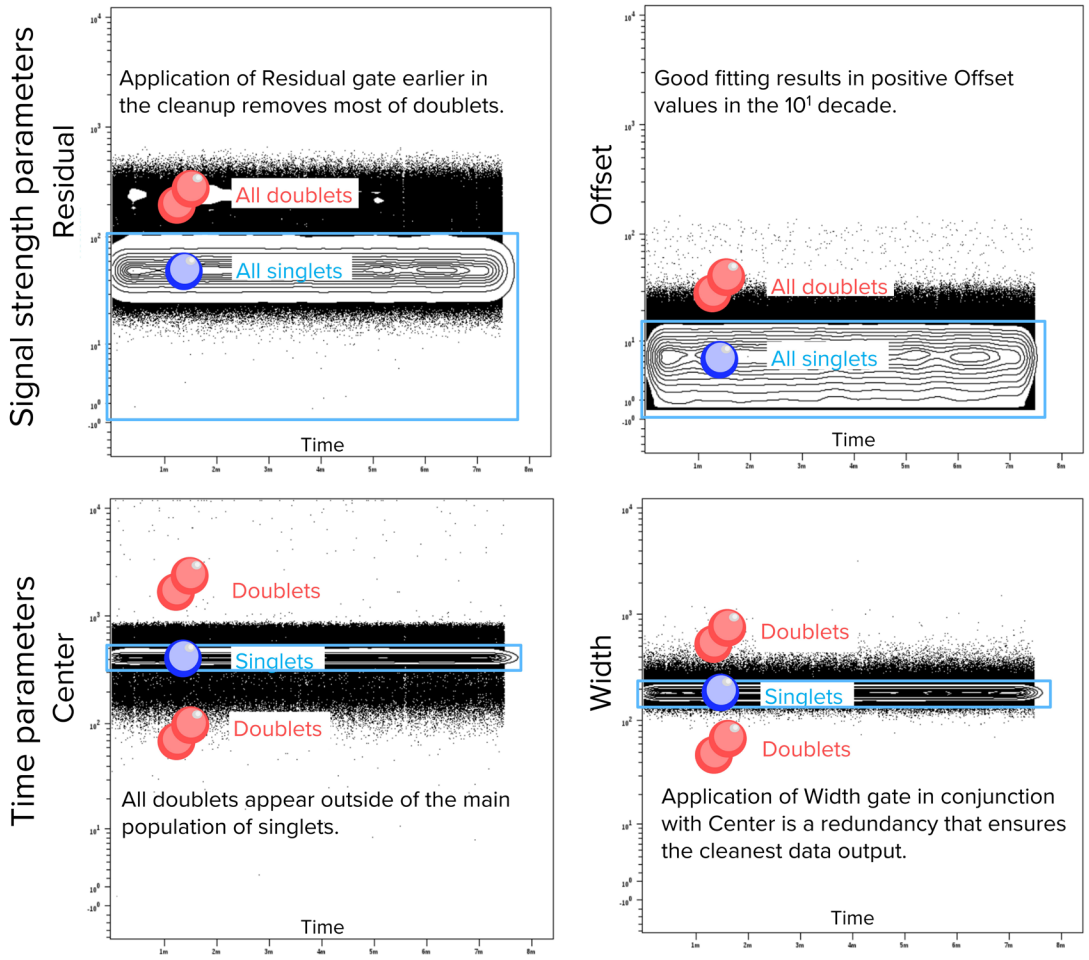
To maximize the efficiency of all parameters to obtain the cleanest data, it is important to alternate the application of signal strength parameters and time parameters. The following is a recommended cleanup strategy, where all gates are applied with Time in the X-axis.

1. Bead exclusion by selecting the strongest-intensity bead channel (140Ce) to remove all bead-associated events including cell-bead doublets
2. Residual
3. Center
4. Offset
5. Width
6. Dead cell exclusion, if applicable
7. Exclusion of remaining doublets by using DNA channel (191Ir)
8. Repeat Step 7 using the second DNA channel (193Ir).

Further reading

For additional basic information regarding event detection and Gaussian parameters (applicable to Helios), see Bagwell et al. *Cytometry Part A* (2020).[4] For an example of how to use Gaussian parameters in a gating strategy for clean singlet-event data, see the Approach to Bivariate Analysis of Data Acquired Using the Maxpar® Direct™ Immune Profiling Assay™ Technical Note (400248).

A



B

$$Residual = \sqrt{\frac{\Delta_1{}^2 + \Delta_2{}^2 + .. + \Delta_n{}^2}{Event\ length}} \times \frac{1}{Amplitude} \times 10^3$$

$$Offset = \left|\frac{\Delta_1 + \Delta_2 + .. + \Delta_n}{Event\ length}\right| \times \frac{1}{Amplitude} \times 10^3$$

$$Center = \frac{t_c}{Event\ length} \times 10^3$$

$$Width = \frac{W}{Event\ length} \times 10^3$$

See previous panel for parameter identification on the biaxial plots.

C

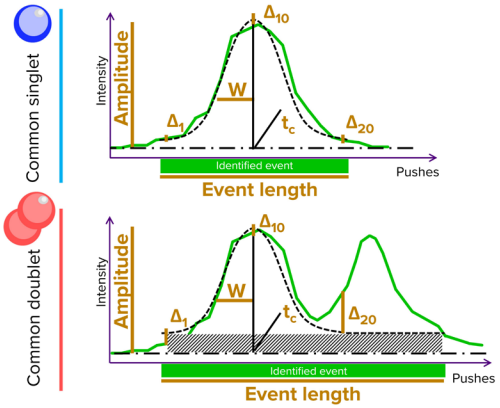


Figure 6. A) Manual gating and identification of singlets and doublets in the biaxial plot based on their Gaussian parameters. **B)** Calculation of reported Gaussian parameters. **C)** Characteristics of the fitting curves are used to calculate reported Gaussian parameters. The gray patterned rectangle in the doublet plot represents the Offset elevation.

NOTE Sometimes it helps to switch to a different style of biaxial plot to gate Center and Width parameters, such as coloring the plots by density, as uncolored contour biaxial plots (as shown in Figure 6A) may obscure population boundaries.

Summary and Conclusion

The new CyTOF XT mass cytometer from Standard BioTools is a powerful single-cell analysis tool for both basic and clinical research. CyTOF XT improves ease of use over previous CyTOF instruments through automation of daily tuning and sample collection as well as on-the-fly signal optimization for up to 23 hr.

This technical note has demonstrated:

- Automation of instrument tuning has improved speed and consistency of results for CyTOF XT. Tuning is flexible and offers optional manual control over calibration parameters. The tuning report also provides more detailed information about the results and QC metrics.
- The new detector voltage optimization algorithm (Auto DV) allows CyTOF XT to sustain the same sensitivity level over extended runs, thereby removing the need for recalibration. Example data prior to normalization demonstrates that a 23 hr acquisition was free of signal drift for all markers in a panel spanning 89–176 amu.
- The calculations of reported Gaussian parameters were improved in CyTOF Software v8.0 to better identify adequate single-cell events in biaxial plots. The software uses an effective gating strategy that consistently obtains clean singlet-only data for use in further downstream analysis.

CyTOF XT, the next evolutionary step in the family of mass cytometers, offers an array of advanced features as described in this technical note.

We invite you to explore the resources available at standardbio.com/cytof.xt to learn more about all of the other exciting and innovative CyTOF XT features and benefits.

References

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2. "Accelerating Medicines Partnership® Detailed Research Plan: RA, SLE and Related Autoimmune Disorders Steering Committee." National Institute of Arthritis and Musculoskeletal Diseases: niams.nih.gov/grants-funding/funded-research/accelerating-medicines.
3. Guo, N., van Unen, V., Ijsselsteijn, M.E. et al. "A 34-marker panel for imaging mass cytometric analysis of human snap-frozen tissue." *Frontiers in Immunology* 11 (2020): 1466.
4. Bagwell et al. "Automated data cleanup for mass cytometry." *Cytometry Part A* 97A (2020): 184–198.

Related Documents

- CyTOF XT: The Next Generation of Mass Cytometry Application Note (FLDM-00462)
- The Benefits of Palladium Barcoding on Data Quality and Workflow Application Note (FLDM-00012)
- Enabling Live-Cell Barcoding with Anti-CD45 Antibodies in Suspension Mass Cytometry Application Note (FLDM-00488)
- CyTOF XT User Guide (FLDM-00254)
- Helios, a CyTOF System User Guide (400250)
- Maxpar Direct Immune Profiling Assay Cell Staining and Data Acquisition User Guide (400286)
- CyTOF Software v8.0 Help for CyTOF XT (FLDM-00045)
- Approach to Bivariate Analysis of Data Acquired Using the Maxpar Direct Immune Profiling Assay Technical Note (400248)

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Or contact: **tech.support@standardbio.com**

CORPORATE HEADQUARTERS
2 Tower Place, Suite 2000
South San Francisco, CA 94080 USA
Toll-free: 866 359 4354 in the US and Canada
Fax: 650 871 7152
standardbio.com

SALES
North America | +1 650 266 6170 | info-us@standardbio.com
Europe/Middle East/Africa/Russia | +33 1 60 92 42 40 | info-europe@standardbio.com
Latin America | +1 650 266 6170 | info-latinamerica@standardbio.com
Japan | +81 3 3662 2150 | info-japan@standardbio.com
China (excluding Hong Kong/Macau) | +86 21 3255 8368 | info-china@standardbio.com
All other Asia-Pacific countries/Australia/India | +1 650 266 6170 | info-asia@standardbio.com

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FLDM-00678 Rev 03