



Flash Memory Summit

# Measuring the Difficulty of Programming 3D NAND

Vic Ye

Manager, NAND Flash Characterization





# Executive Summary

## Problem:

- Read retry operations are more frequent for 3D NAND than for 2D NAND, because 3D NAND is much more difficult to program consistently than 2D NAND. This reduces the reading speed and increases the power consumption of the system.

## Our goal:

- To develop a new set of metrics to measure the quality of program operation more accurately, and then, with this method, to improve program and read operation, in order to avoid read retry as long as possible.

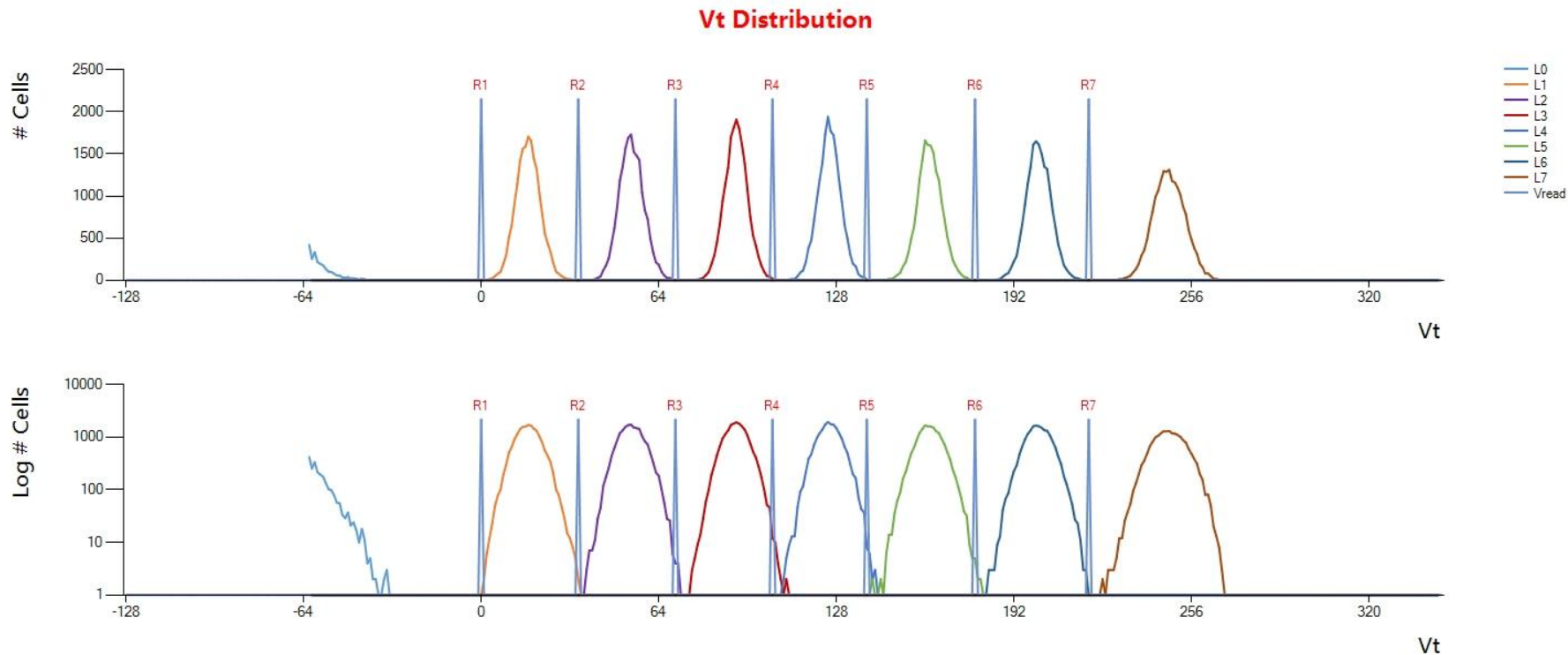


# Outline

- Different programming results on 3D NAND
- The basic approaches to measure program results
- “Valid window” and “Central point”
- Applications: adjustment, sorting, RRT (Read Retry Table) development

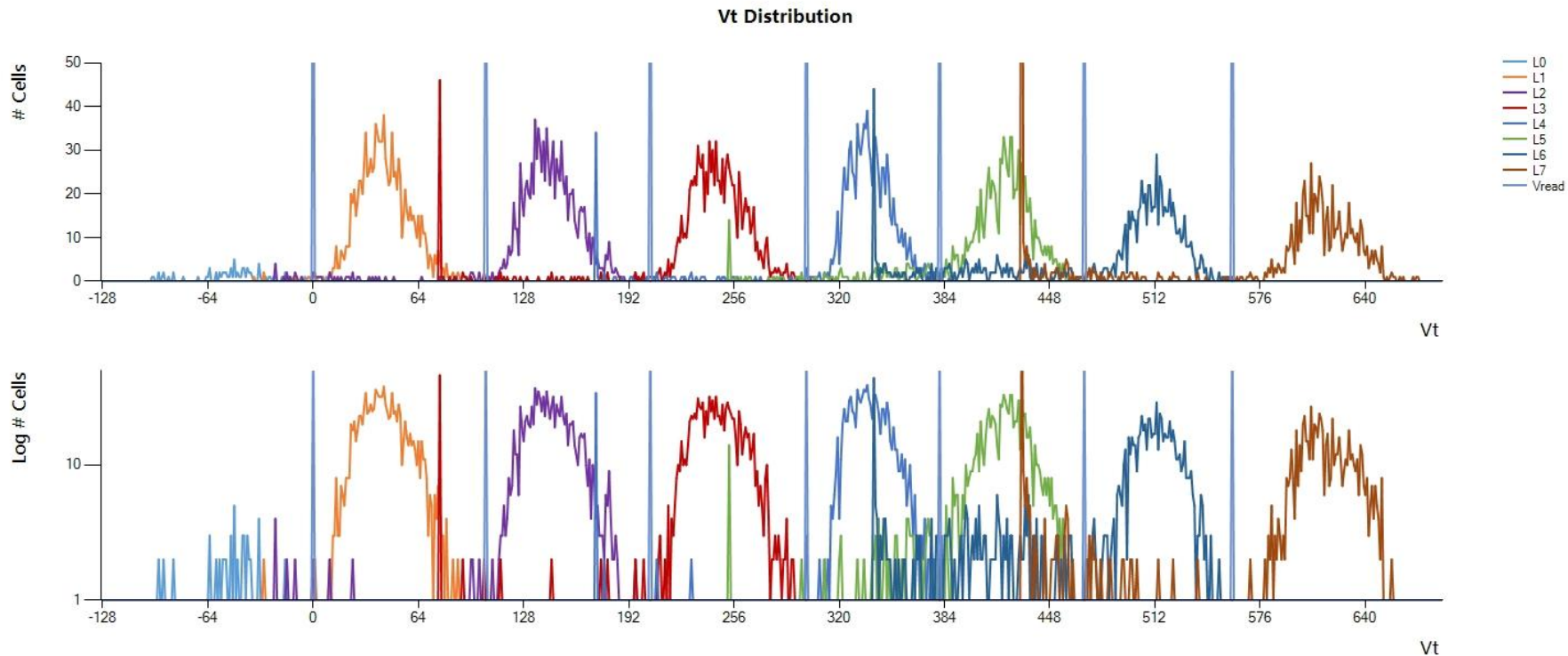


# Example 1: looks good



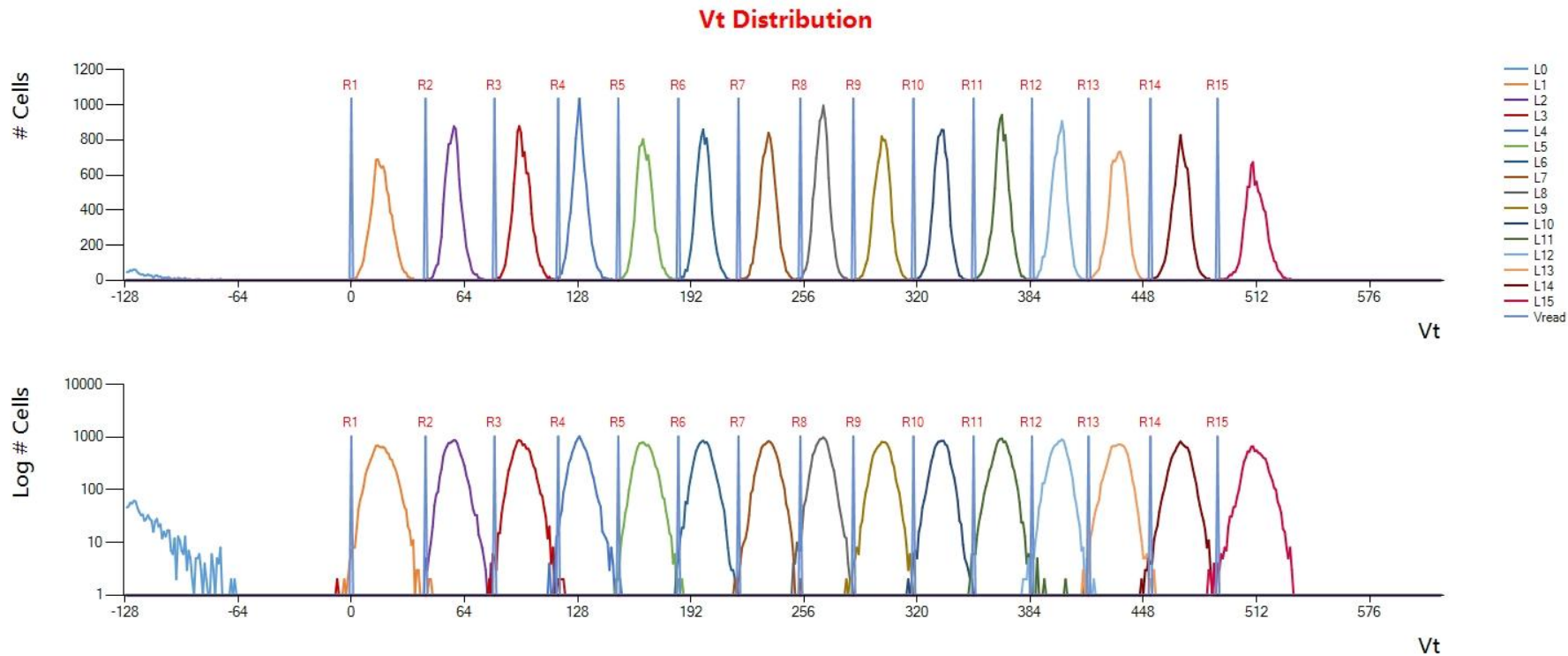


# Example 2: looks bad





# Example 3: ?





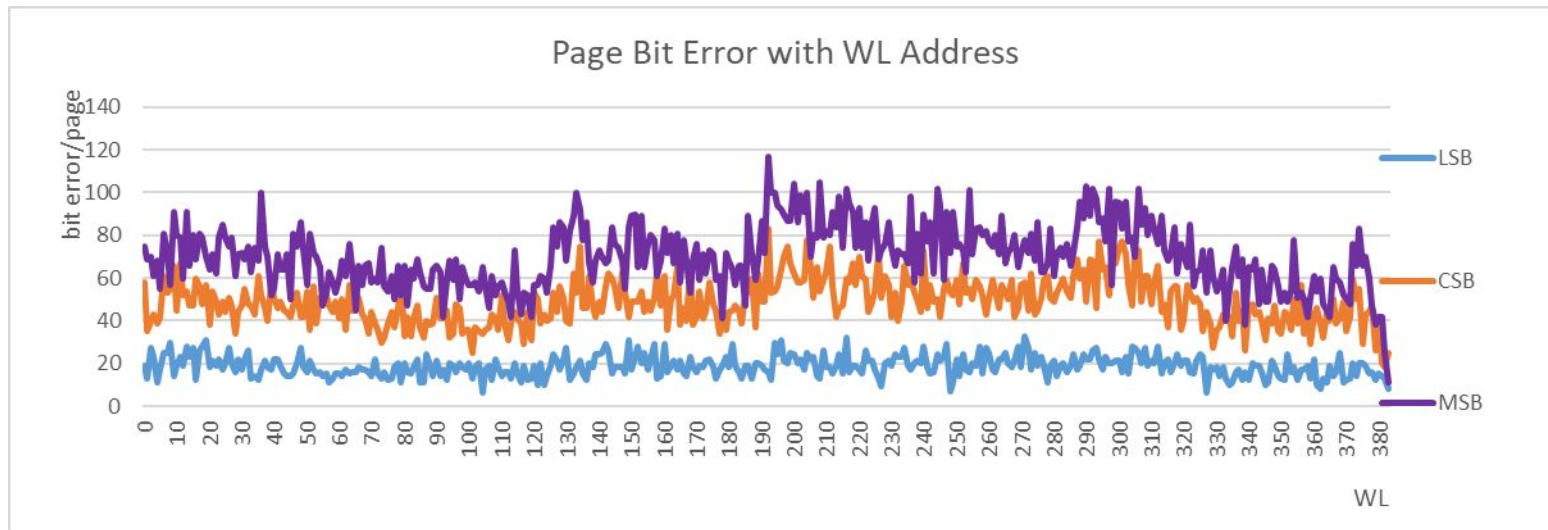
Flash Memory Summit

# How to define the quality of program operations automatically?



# The basic approach

- Count the number of error bits of every page at default Vread







# The less error bits, the better program quality?

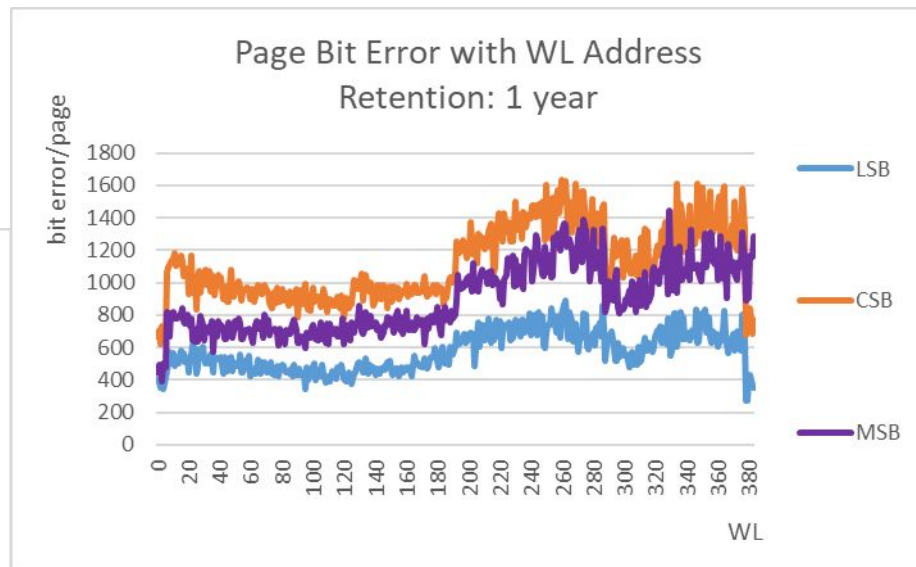
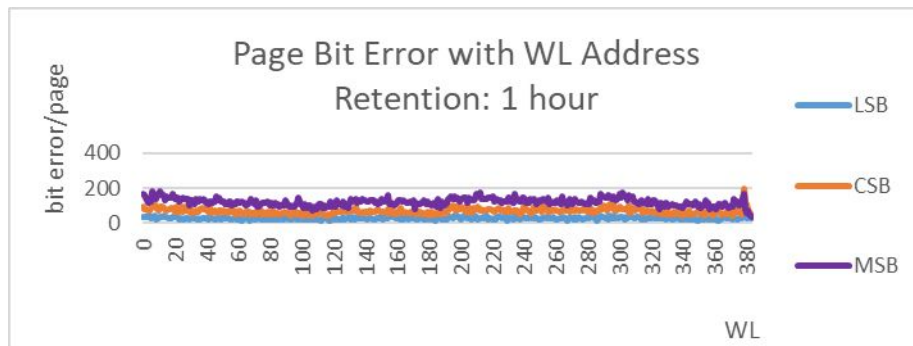
- No! A good program is to keep the error rate as low as possible for as long as possible, rather than being low at the beginning and getting very high soon.
- The data is seldom read out immediately after programming. Some will be read out after months, even years.
- Maintaining a low error rate over a long period of time means fewer read retries and data migration from one block to another, which further means higher reading speed and lower power consumption.



# Bit error at different retention

## Flash Memory Summit

For some 3D NAND, after one year retention, the number of bit errors will exceed the capability of normal ECC engine.



In such case, read retry is required, which will slow down the reading speed and increase the power consumption of the system, for one read retry process means several, tens, or even over one hundred page readings.



How to program to keep the error rate as low as possible for as long as possible?

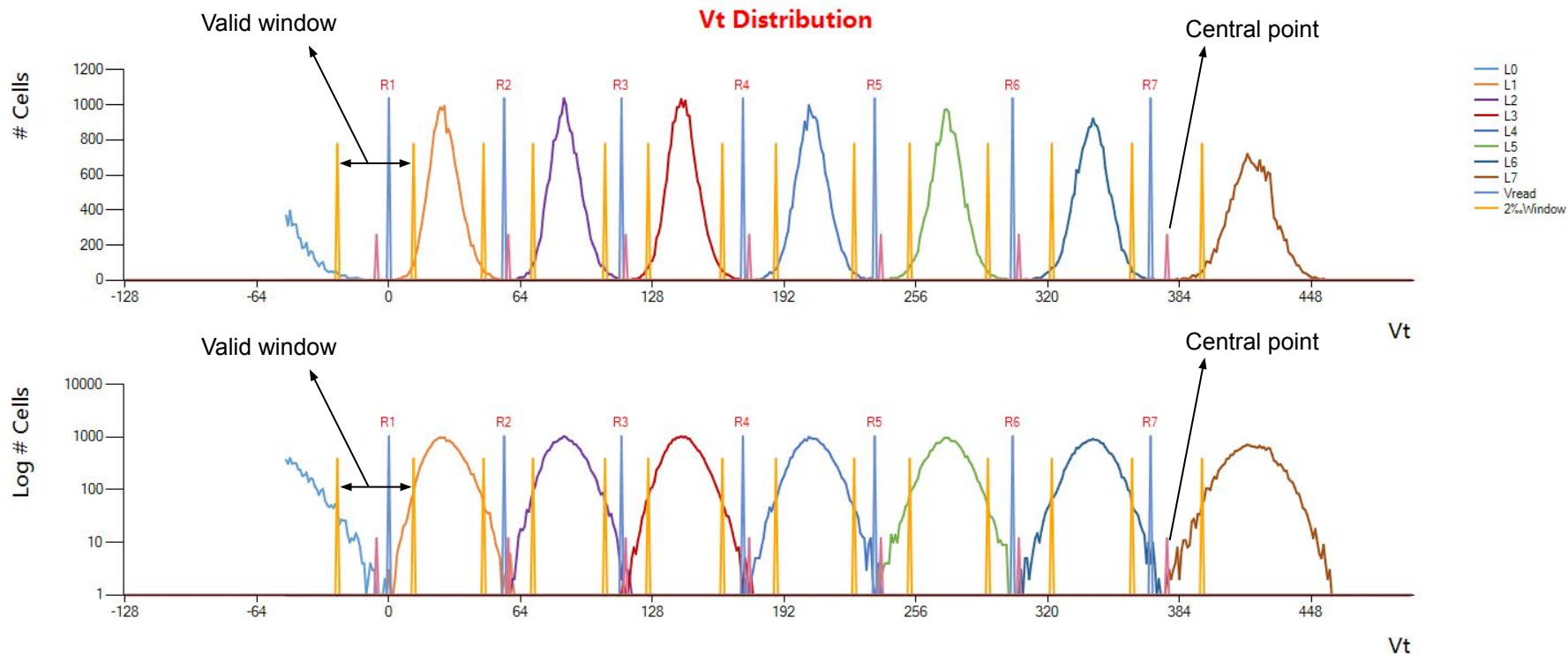


## “Valid window” and “Central point”

- “Valid window” is a window between two adjacent level in which the bit error rate is within a certain range. (Usually 0.1% or 0.2%)
- “Valid window” is also known as read margin. A larger window indicates higher error correction probability and less number of read retry (or no need read retry).
- “Central point” is the middle point of the valid window.



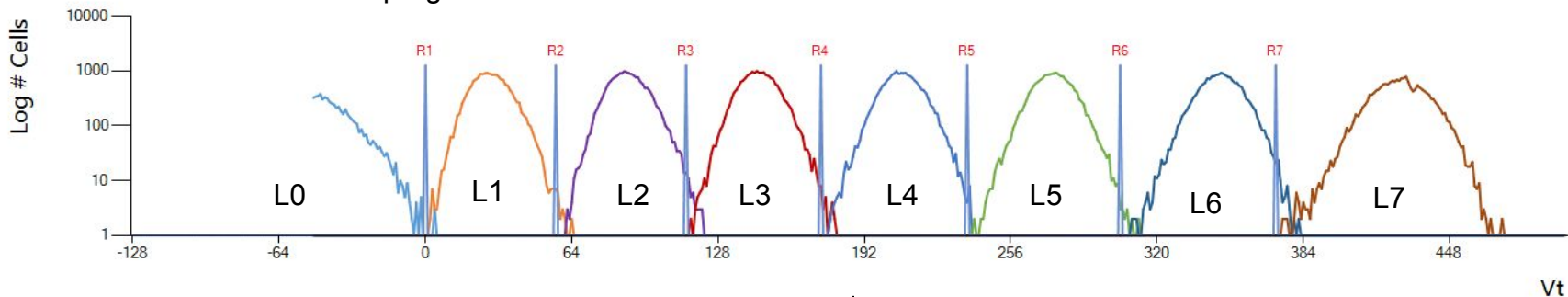
# “Valid window” and “Central point”



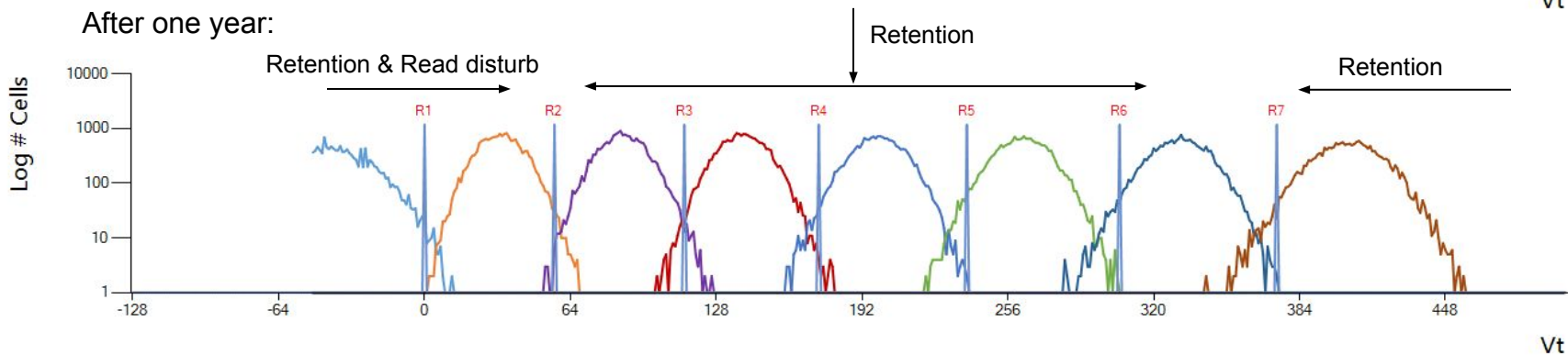


# Level shift

V<sub>th</sub> distribution after program:

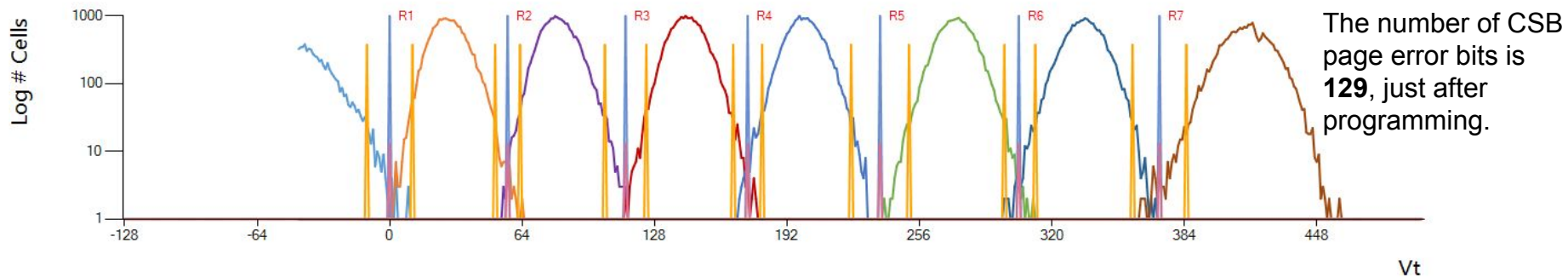


After one year:

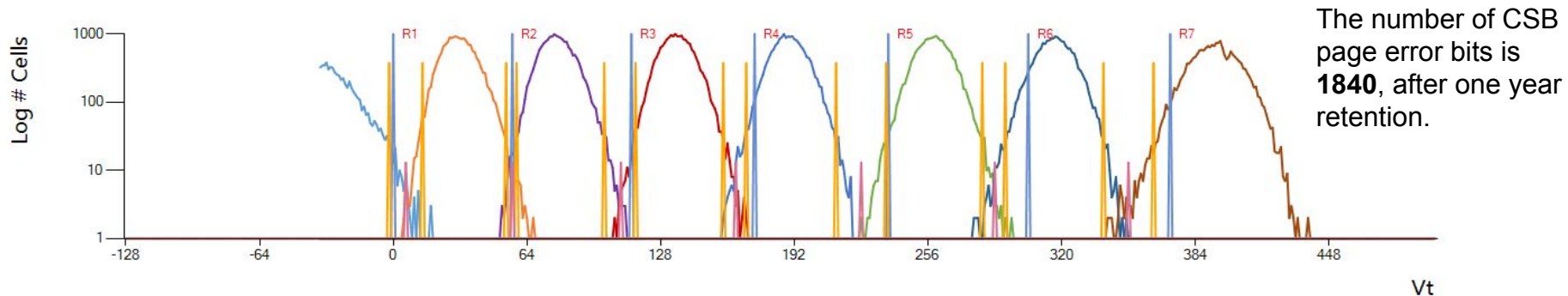




## If the default $V_{read}$ is at the center after programming



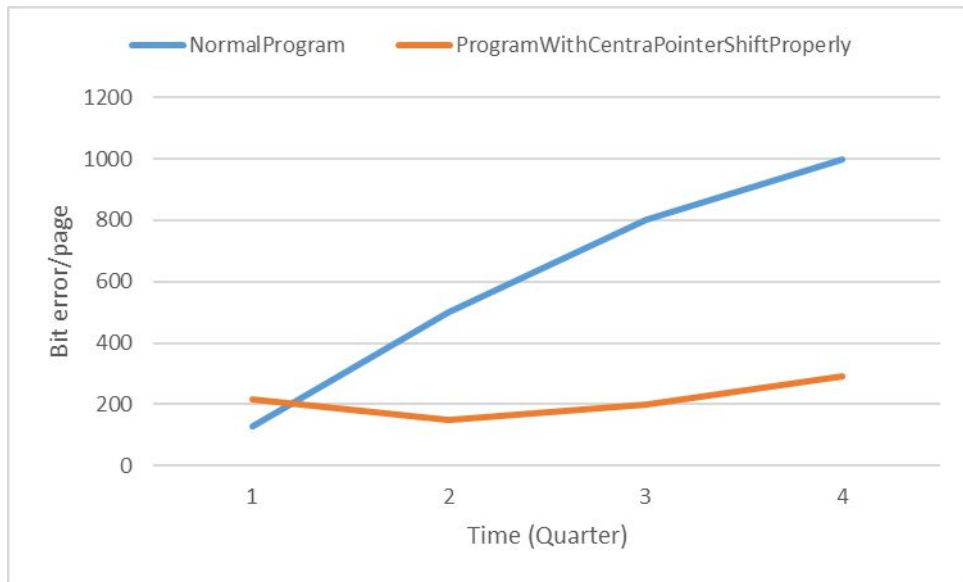
## Then number of error bits will raise sharply after a year retention





# How to improve program quality

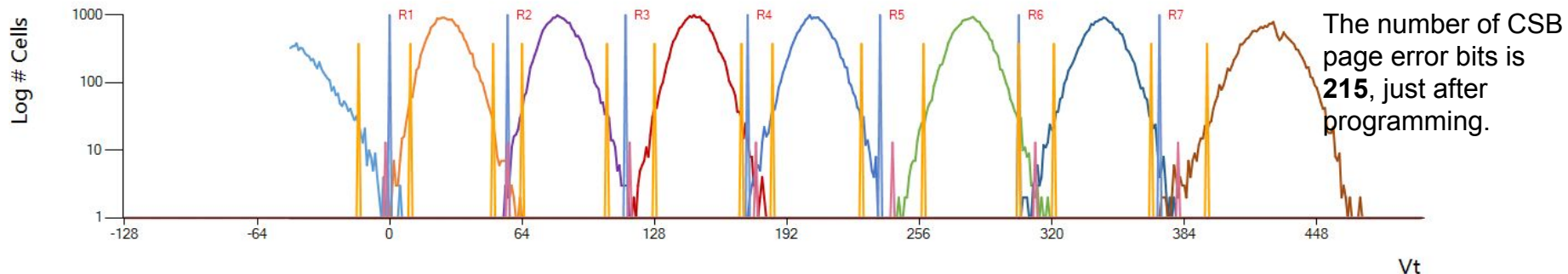
- Make the valid window bigger, but it will take longer time to program.
- Shift the central point properly, away from default Vread, the bit error rate can be lowered and then raised with retention and read disturb.



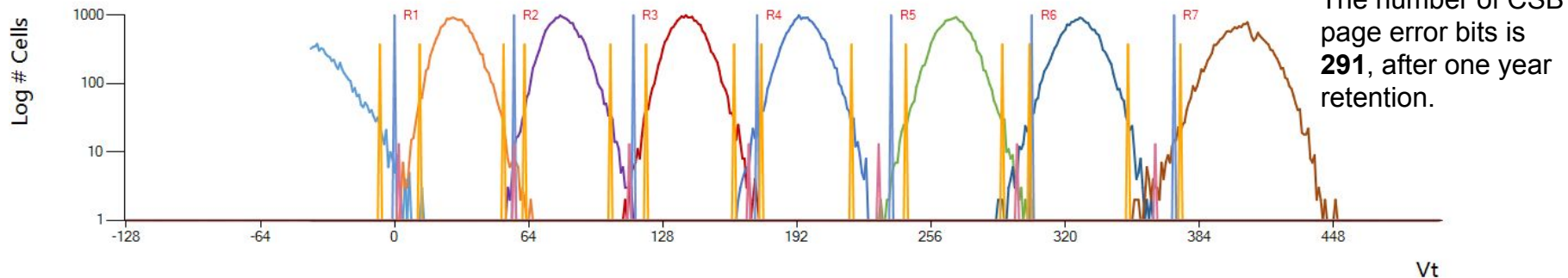




If the central pointer shift properly by programming,



Then number of error bits will raise slowly after one year retention.  
If the retention is within half year, it may even decrease.





If you don't know how to adjust the levels, the easiest way is to adjust the default Vread. Only the direction of adjustment is opposite to that of level adjustment.



# Application

- Adjustment: to adjust parameters to get better results; but we have to trade off between program time and program quality;
- RRT (Read Retry Table) development;
- Sorting: to screen out good chips (or bad chips)



Flash Memory Summit

# Thank you.

Feel free to email me with any questions & feedback

[vic.ye@yeestor.com](mailto:vic.ye@yeestor.com)