Improving NAND Flash Reliability with Rank Modulation

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joint work with

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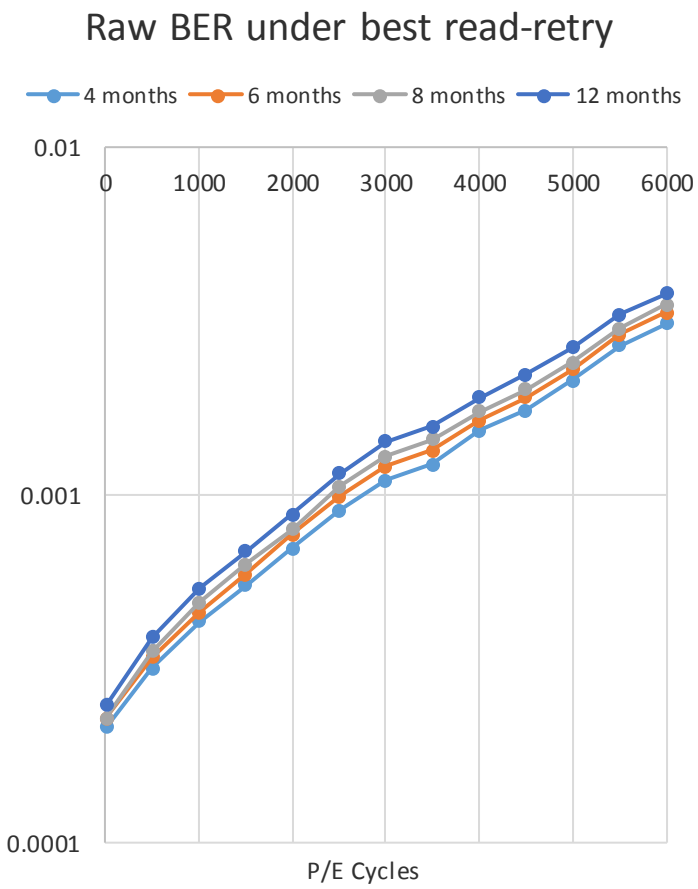
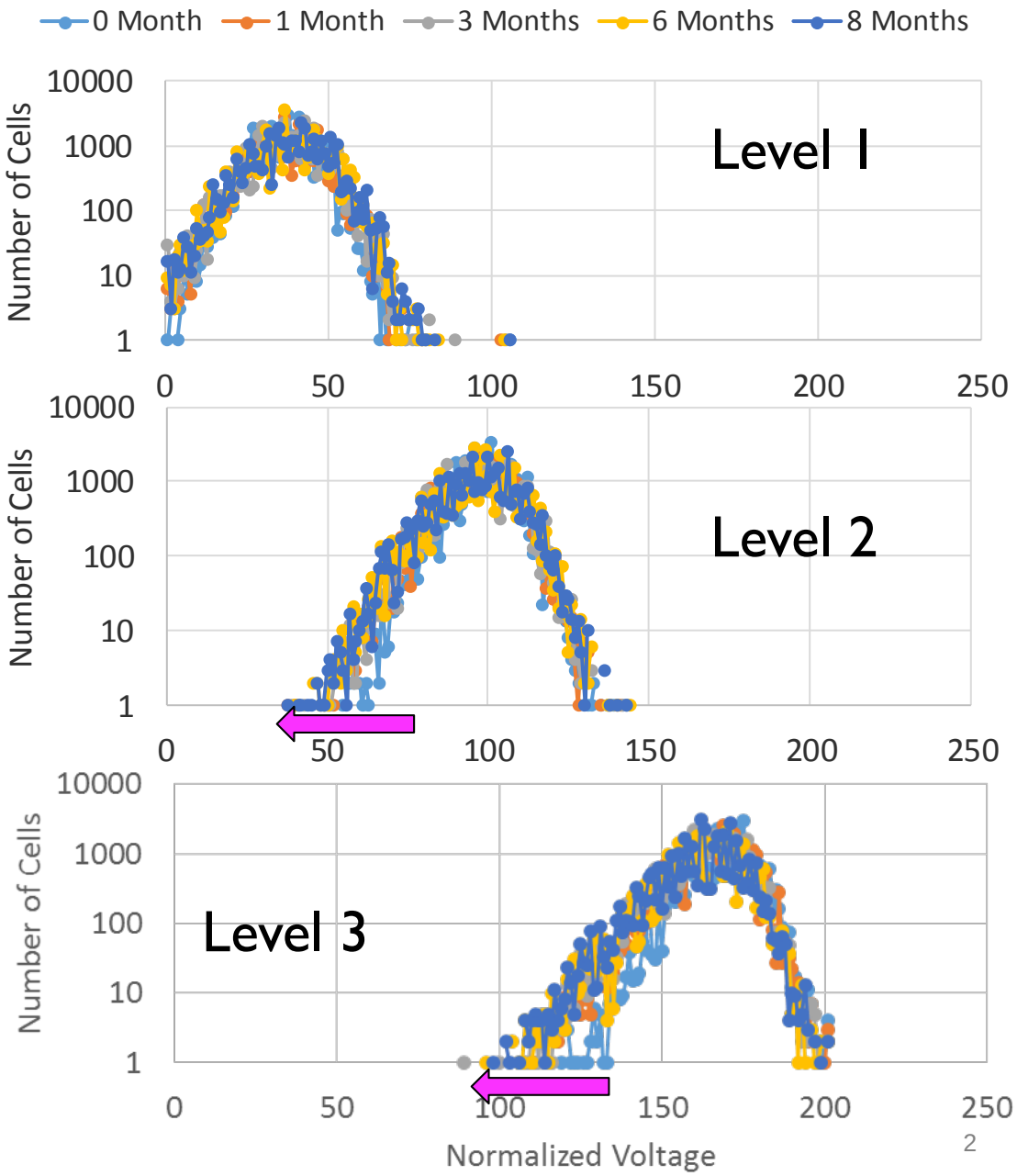
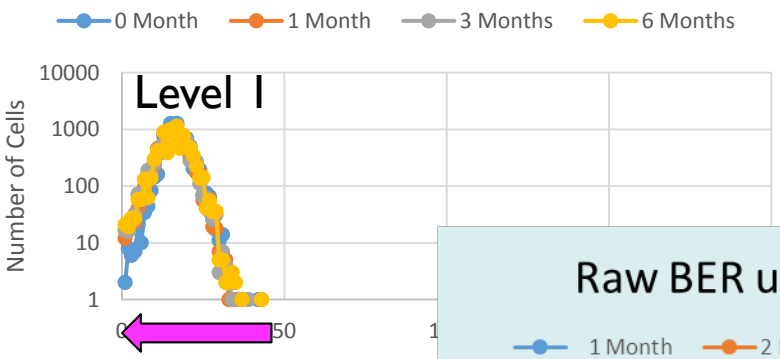
Asymmetric Voltage Drift in 1x nm MLC NAND

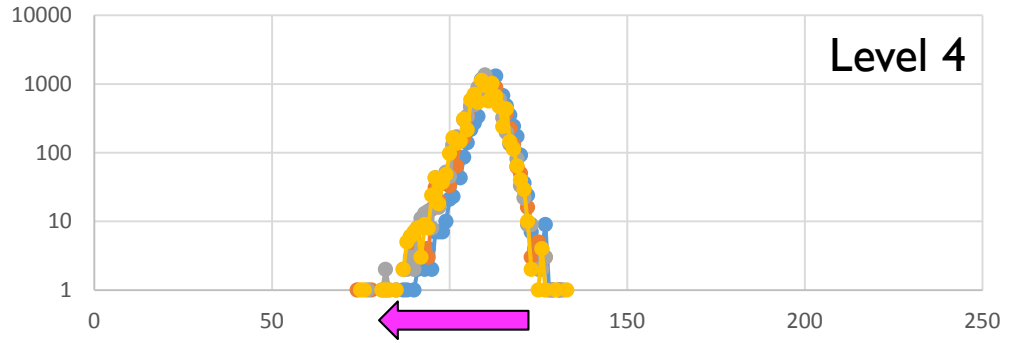
- High temperature data retention measured in our lab. (following JEDEC standard)

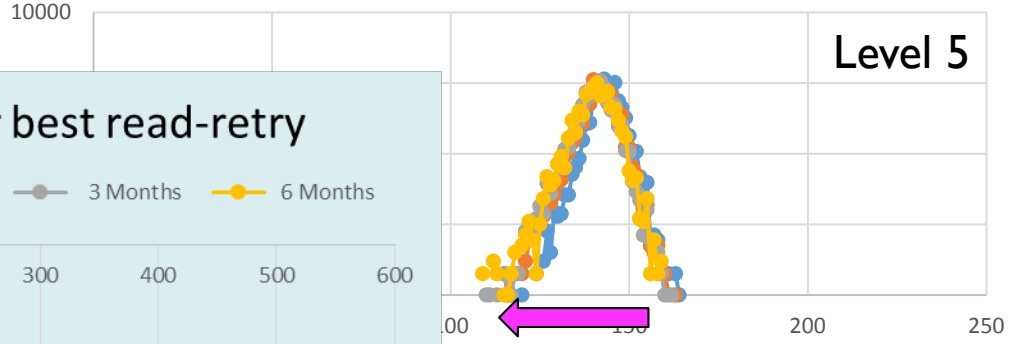


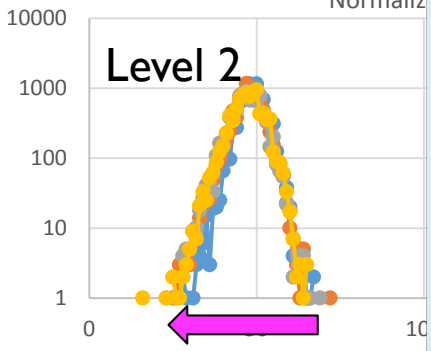


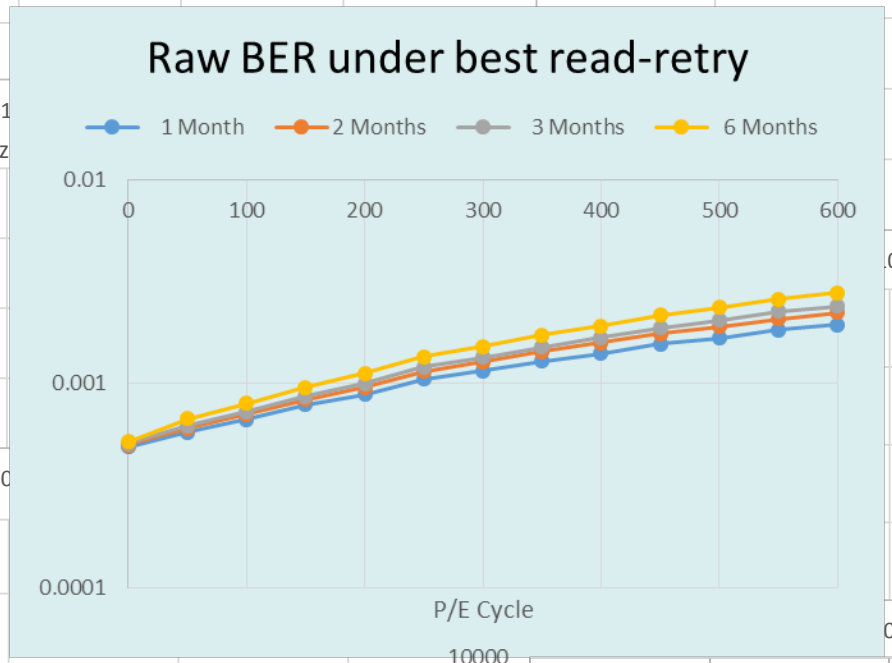
Asymmetric Voltage Drift in 1y nm TLC NAND

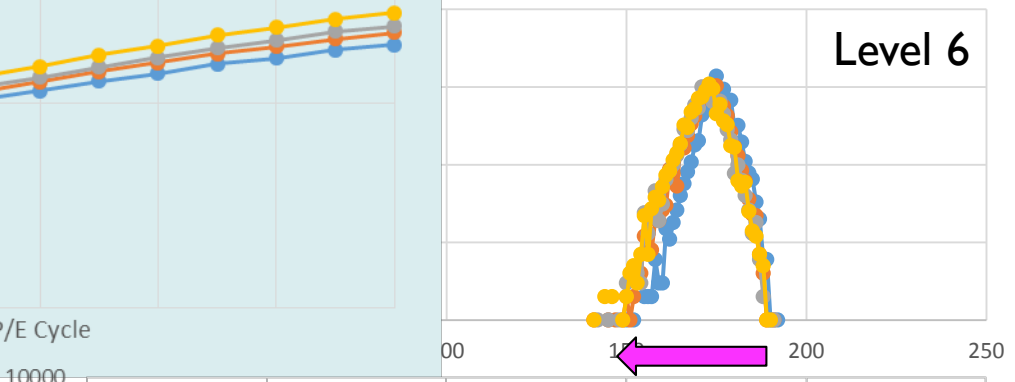


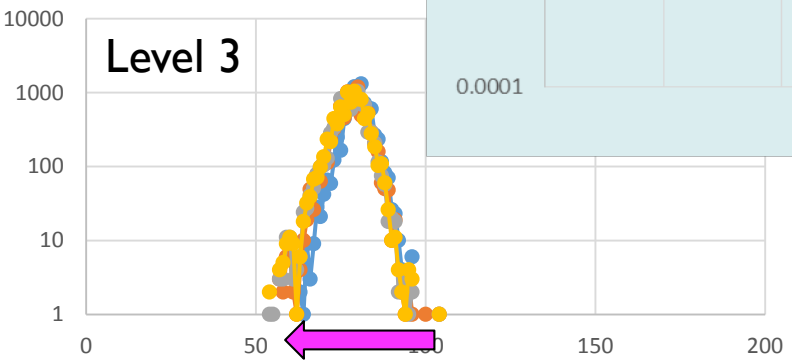


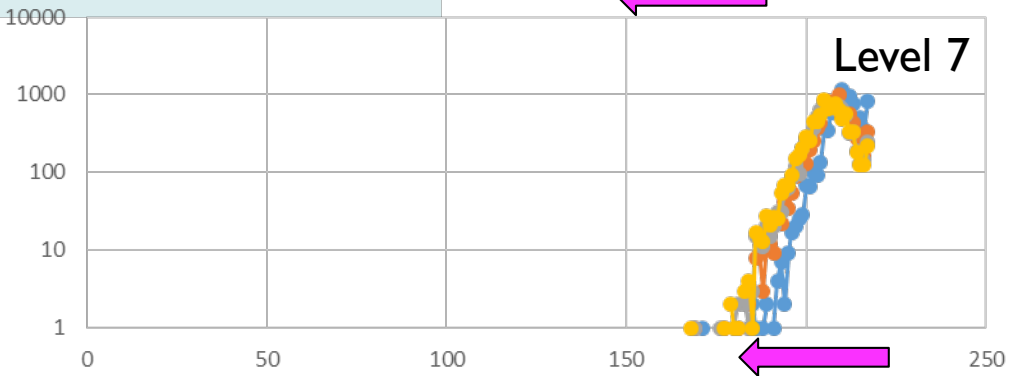




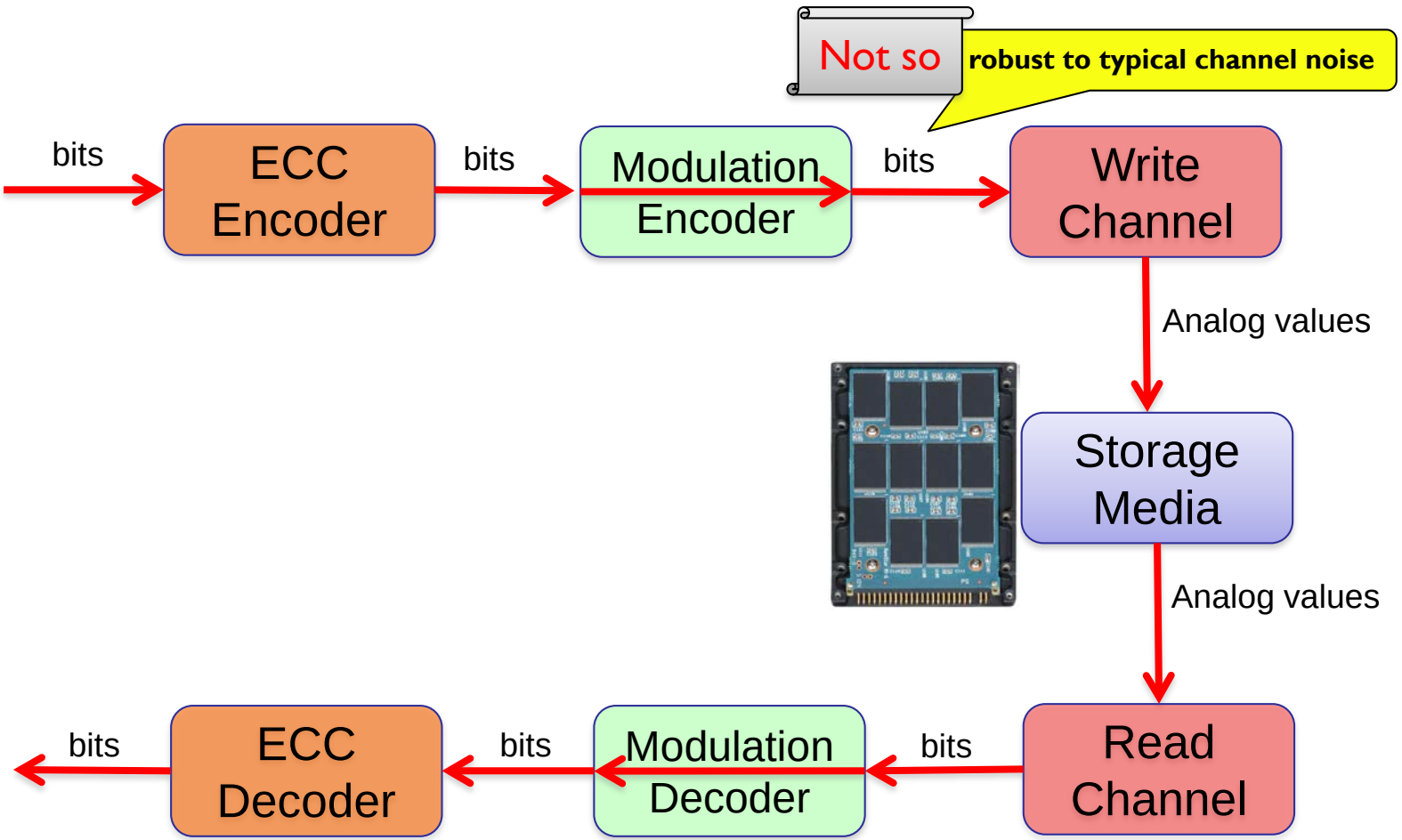








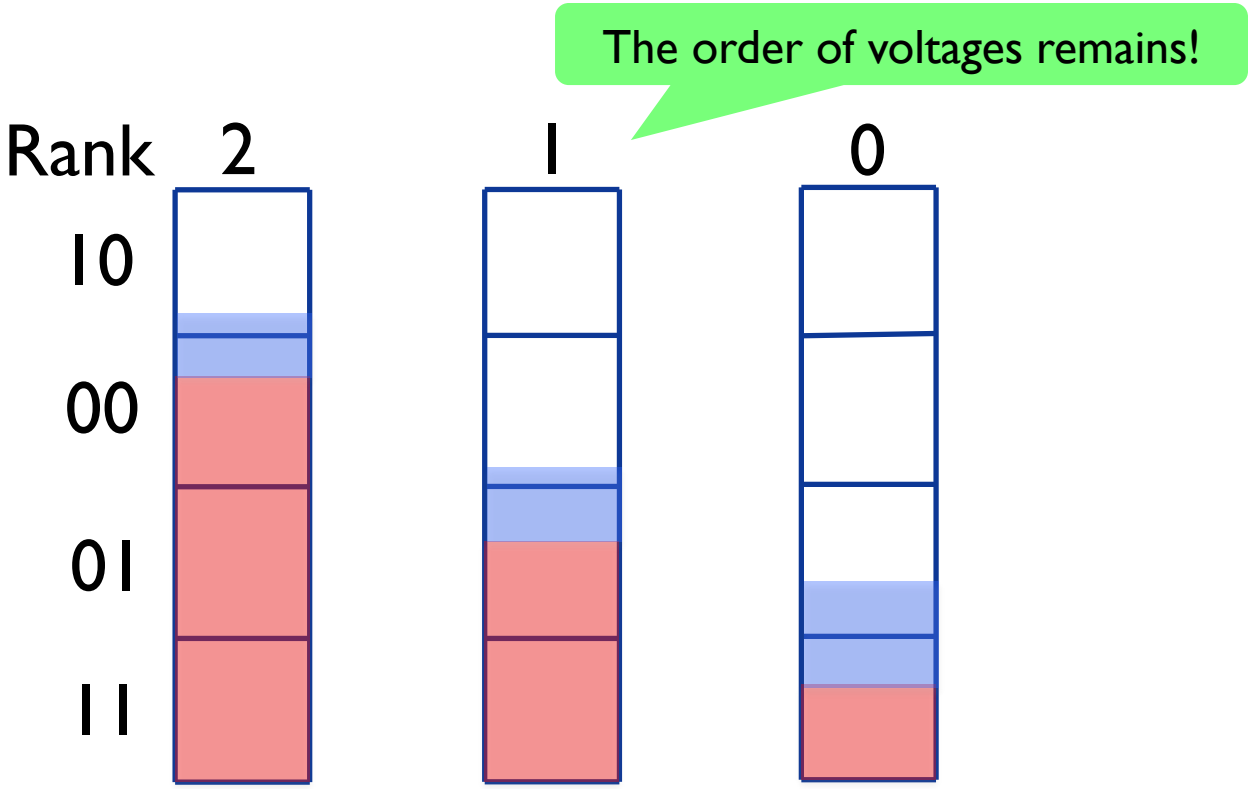
Flash (of High Density) Needs Modulation



Adding Modulation for Flash

- Simple
  - Easy to implement
  - Easy to teach
- Robust against typical errors
  - Programming interference
  - Charge leakage

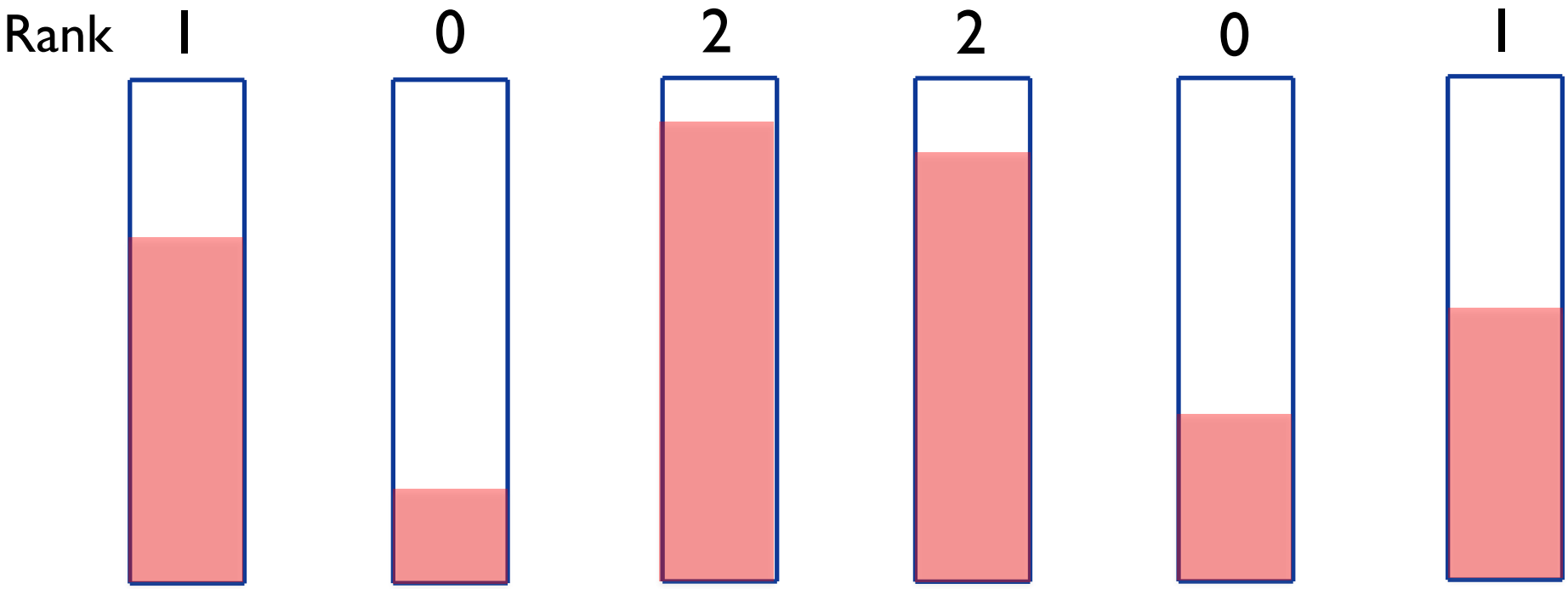
Use Relative Order to store data



Data Retention

A. Jiang, R. Mateescu, M. Schwartz, and J. Bruck, "Rank Modulation for Flash Memories," IEEE Transactions on Information Theory , vol.55, no.6, pp.2659-2673, June 2009

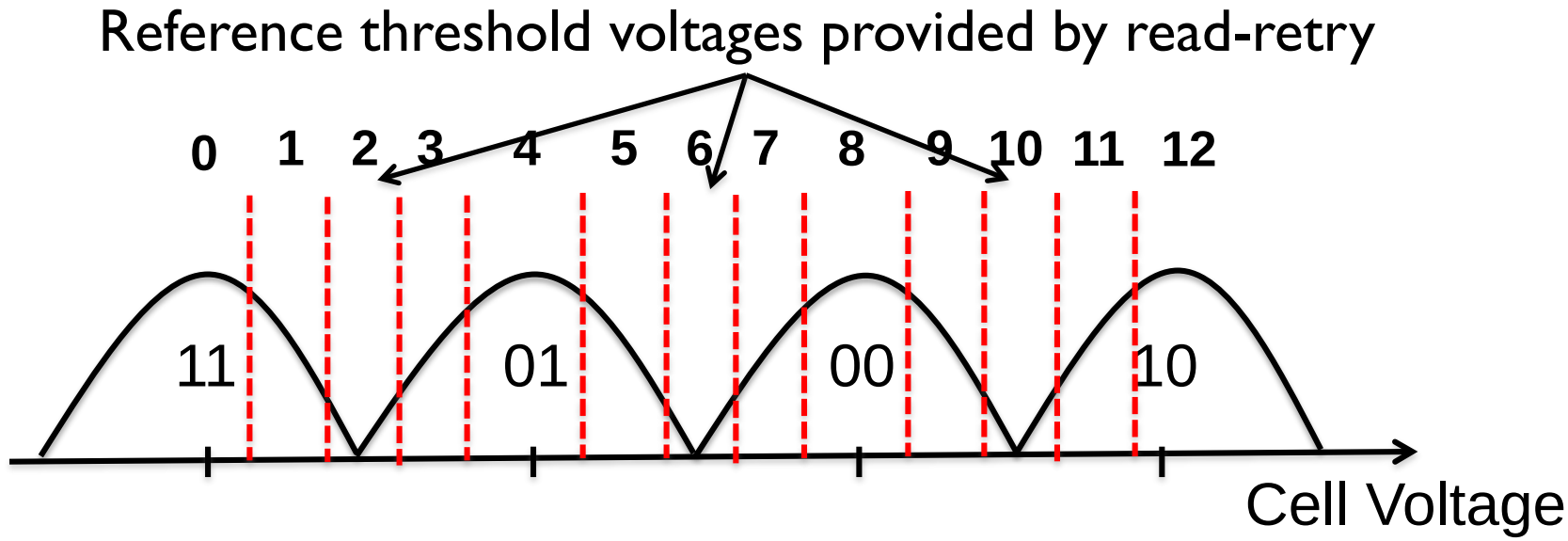
More Cells in Each Rank for Higher Storage Capacity



Example: 3 Ranks, 2 Cells/Rank

E. En Gad, A. Jiang and J. Bruck, "Trade-offs between Instantaneous and Total Capacity in Multi-Cell Flash Memories," ISIT 2012.

Rank Modulation in MLC



Location	0	1	4	5	8	9	12	12
Rank	0	0	1	1	2	2	3	3

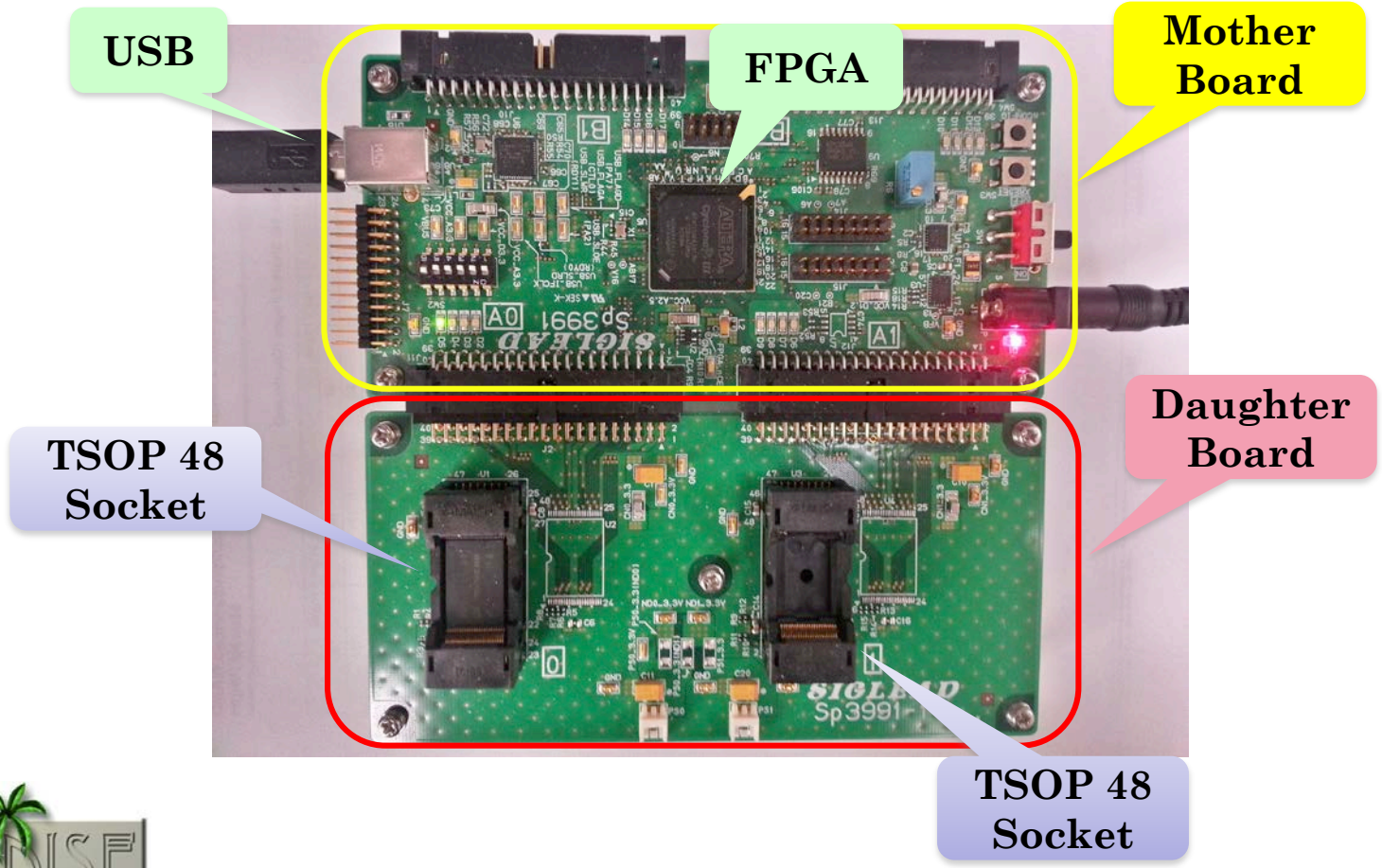
Example: 8 cells, 4 ranks

(0, 1, 0, 3, 2, 2, 1, 3)

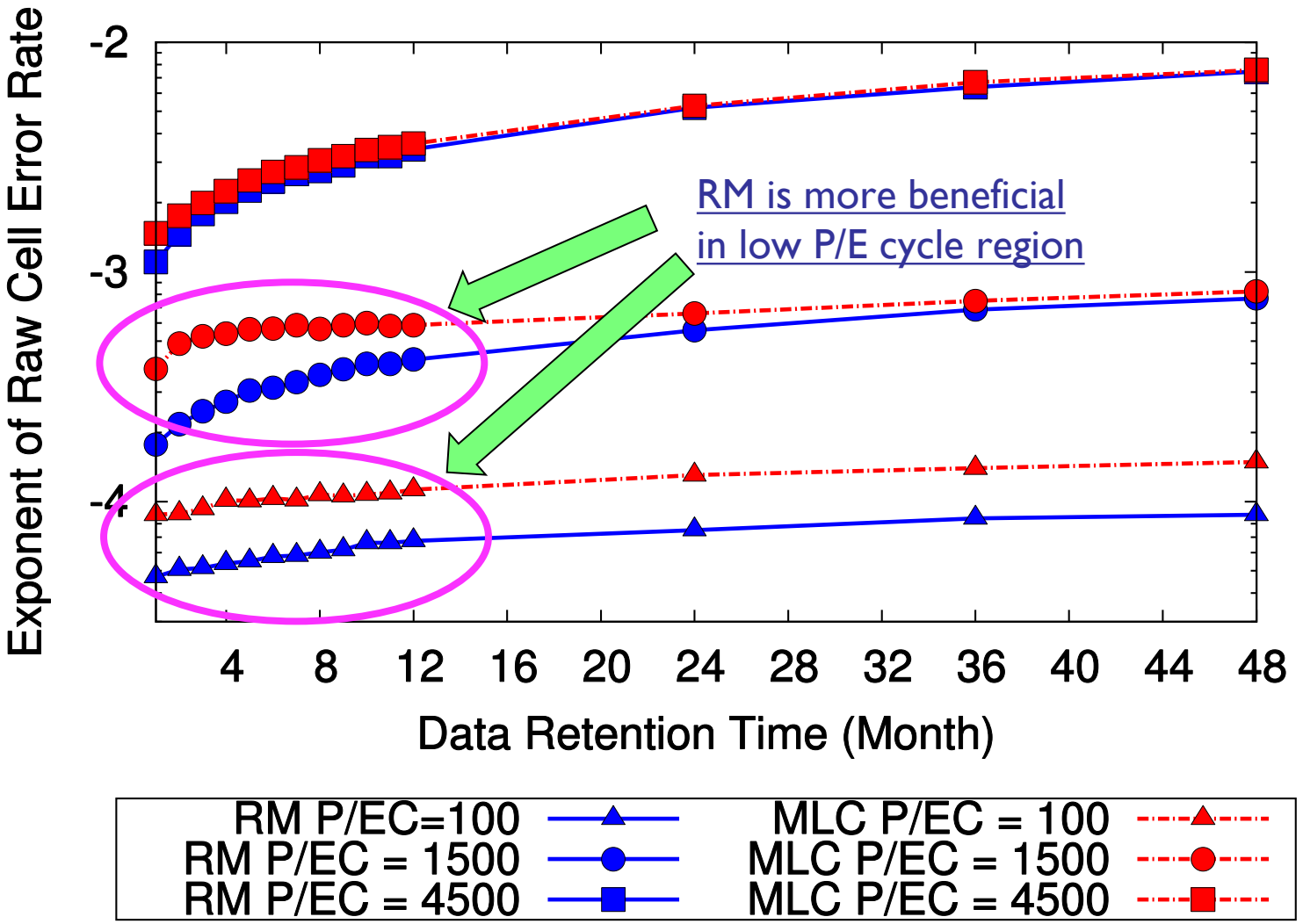
Input Rank Modulation Code

NAND Flash Tester

- SigNAS-II
  - FPGA based tester made by Siglead Inc. (Japan)



How often do cells' voltage order switch?



Y. Li *et al.*, "implementing rank modulation," NVMW 2015.

Flash-based Archival Storage

- Archival data
  - "Write-once read-never"
  - Long data retention time (> 100 years)
  - High reliability (UBER < 1e-15)
- Archival storage using flash
  - Pros
    - random access, efficient data dedup, low power
    - save more on the cost of cooling, power, and form factors than HDD-based archival system[1]
    - No mechanical parts
  - Cons
    - Expensive (but price is decreasing rapidly!)
    - Not reliable
  - Flash only needs to survive small number of P/E cycles.

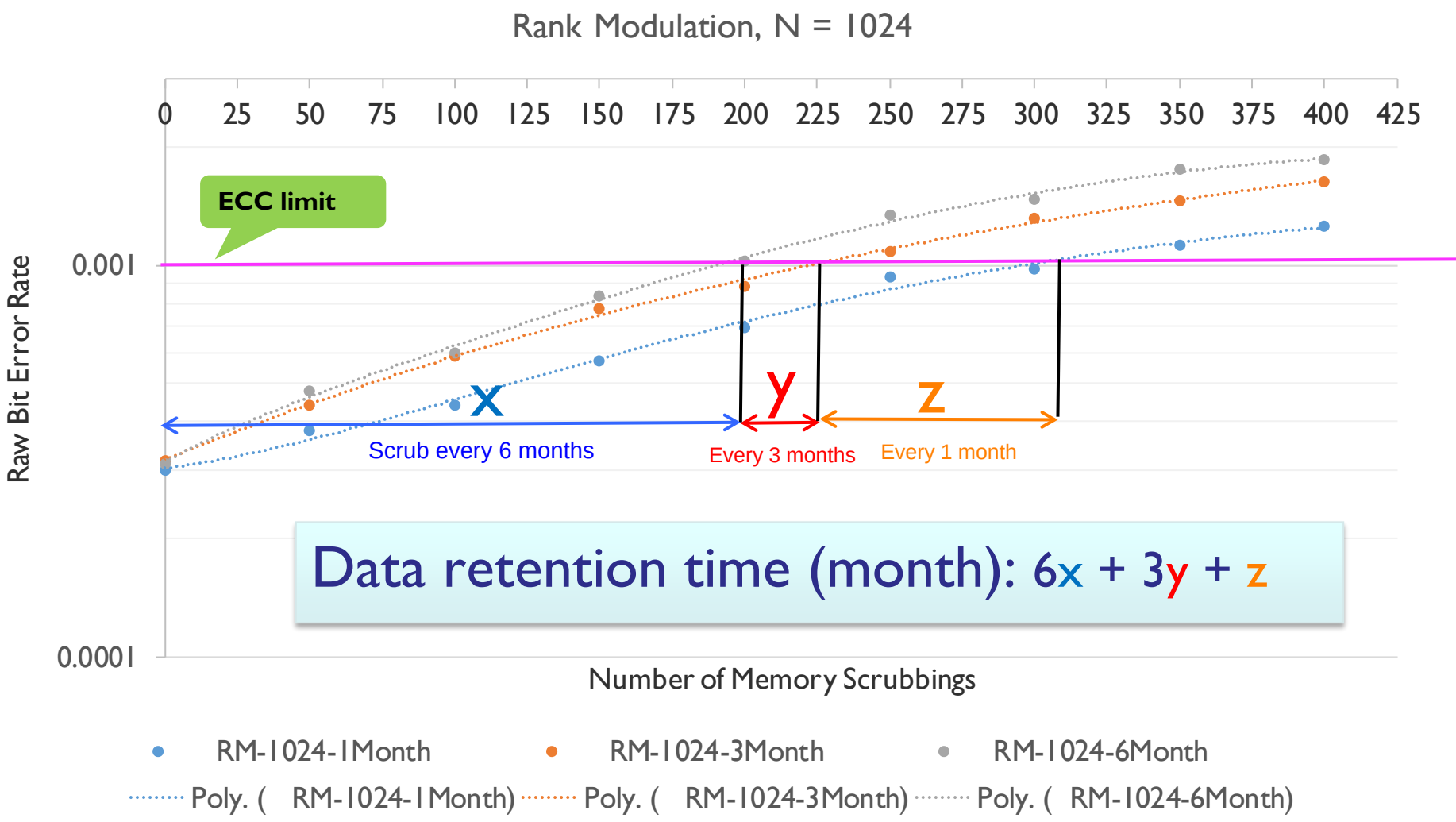
[1] P. Gupta *et al.*, "An economic perspective of disk vs. flash media in archival storage," in *Proceedings of the 22th IEEE International Symposium on Modeling, Analysis, and Simulation of Computer and Telecommunication Systems*, Sep. 2014.

Solution: Rank Modulation + Memory Scrubbing

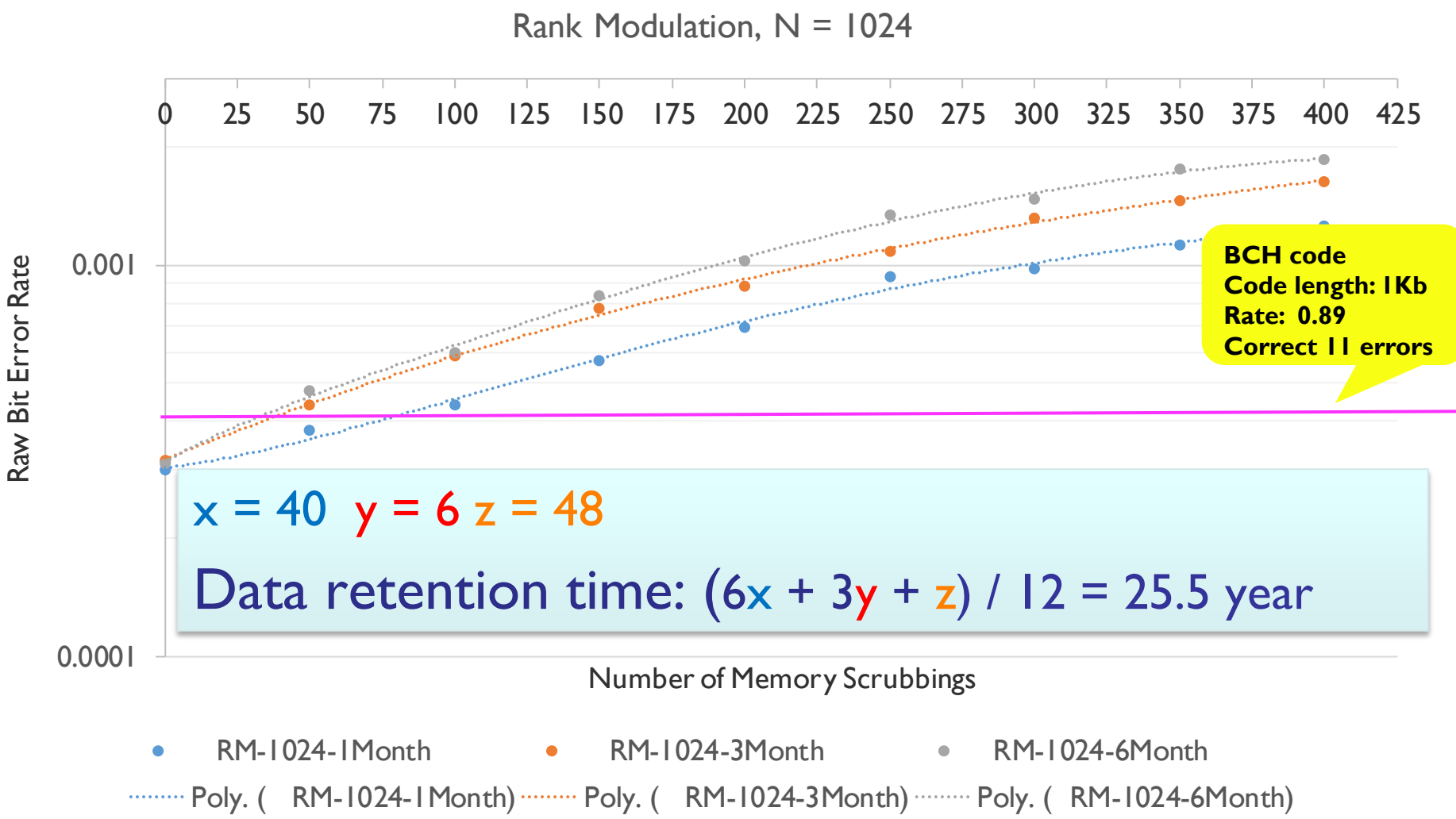
- Our flash-based archival storage solution uses
  - Rank modulation to store data
  - Memory scrubbing to refresh data
    - Scrubbing frequency is adaptive [2]
  - Low-cost ECC
    - Easy to implement, e.g., BCH
    - High code rate (~ 0.9)
    - Shorter code length (~ 200b – 1Kb)
    - Very low decoding and encoding complexity
      - suitable for software implementation
  - High density flash (e.g. TLC)

[2] Y. Cai *et al.*, "Flash Correct-and-Refresh: Retention Aware Error Management for Increased Flash Memory Lifetime," ICCD 2012.

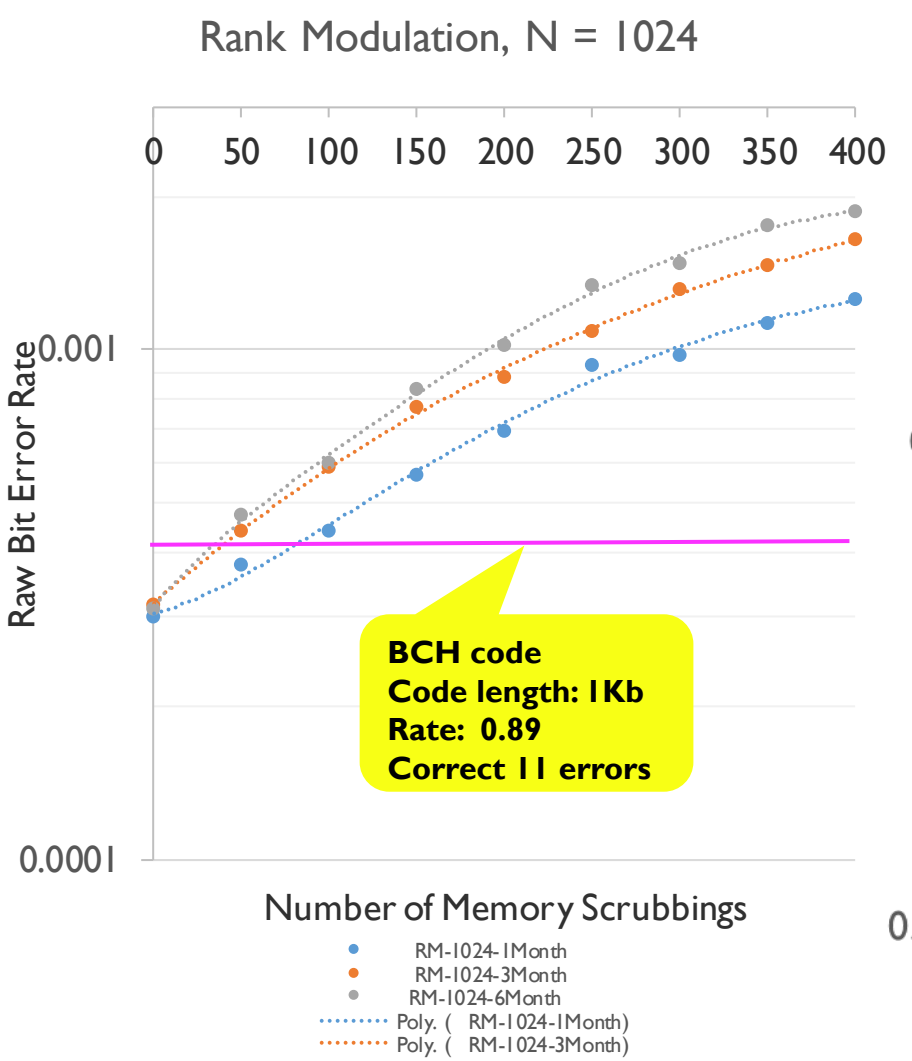
Data Retention Performance on 1x nm TLC

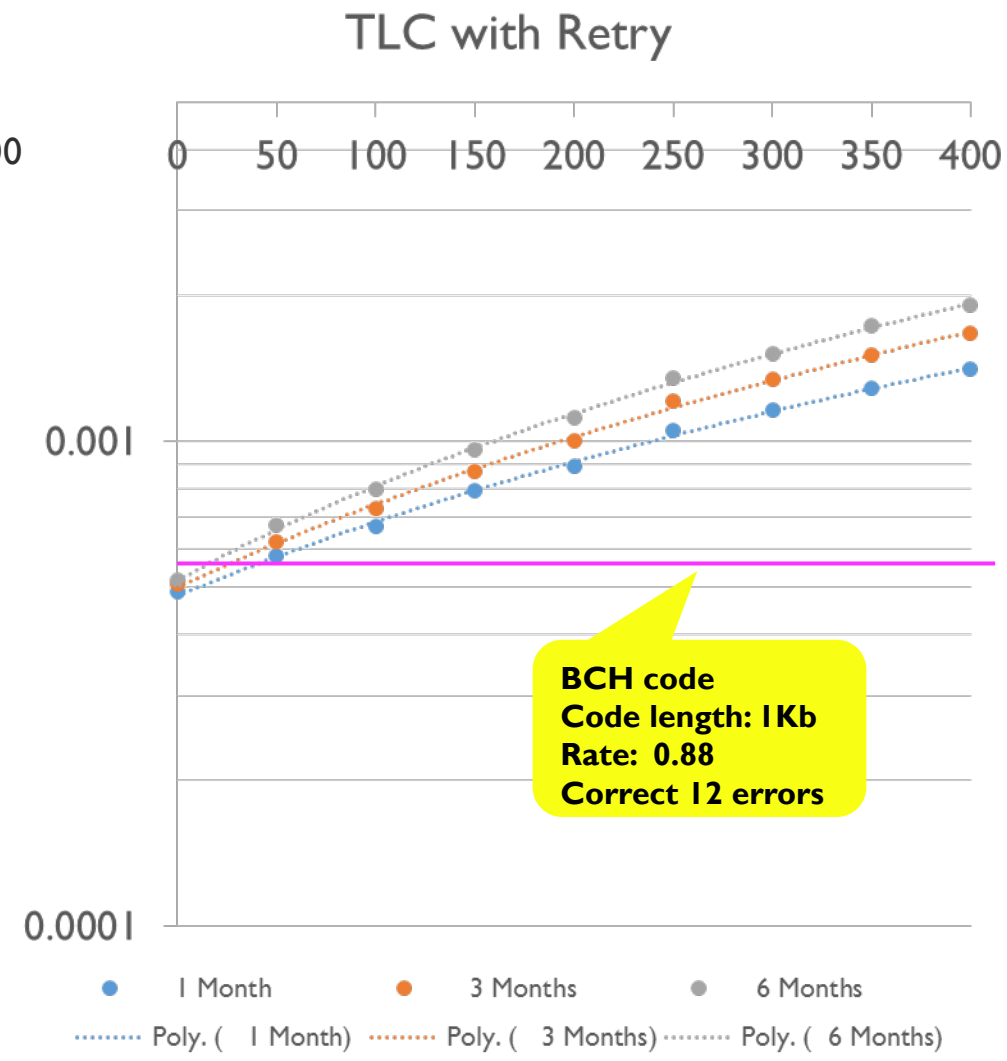


Data Retention Performance on 1x nm TLC



Comparison based on Same Coding Redundancy



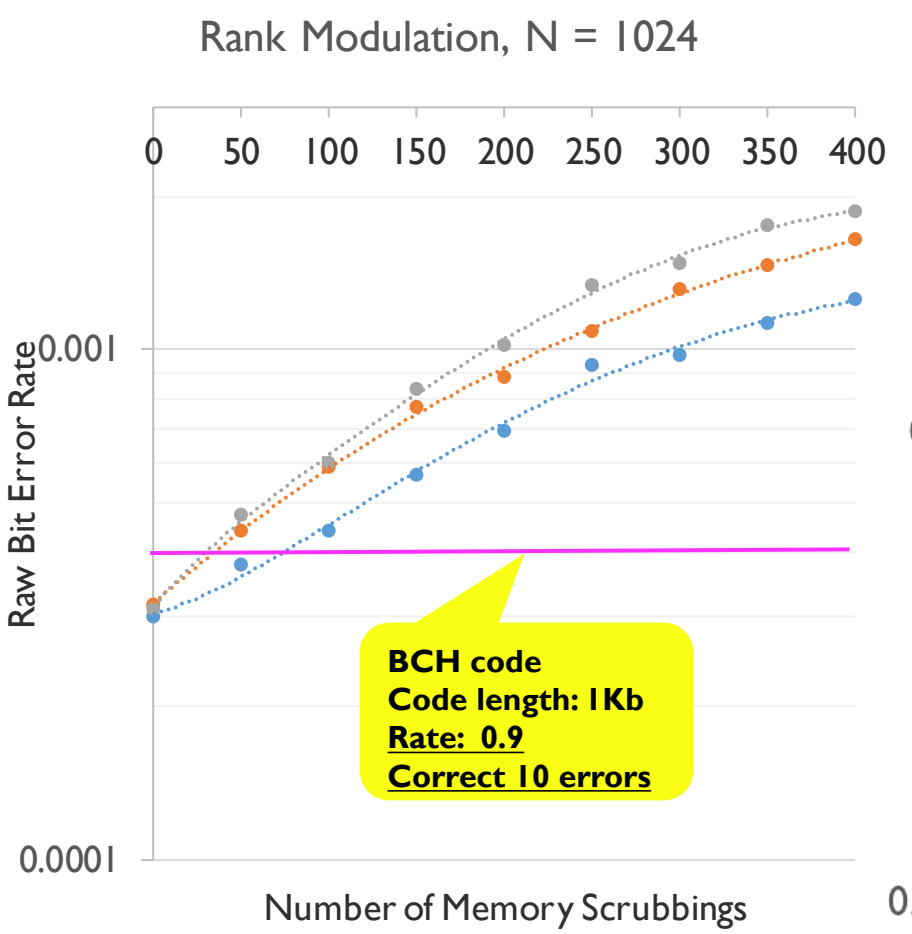


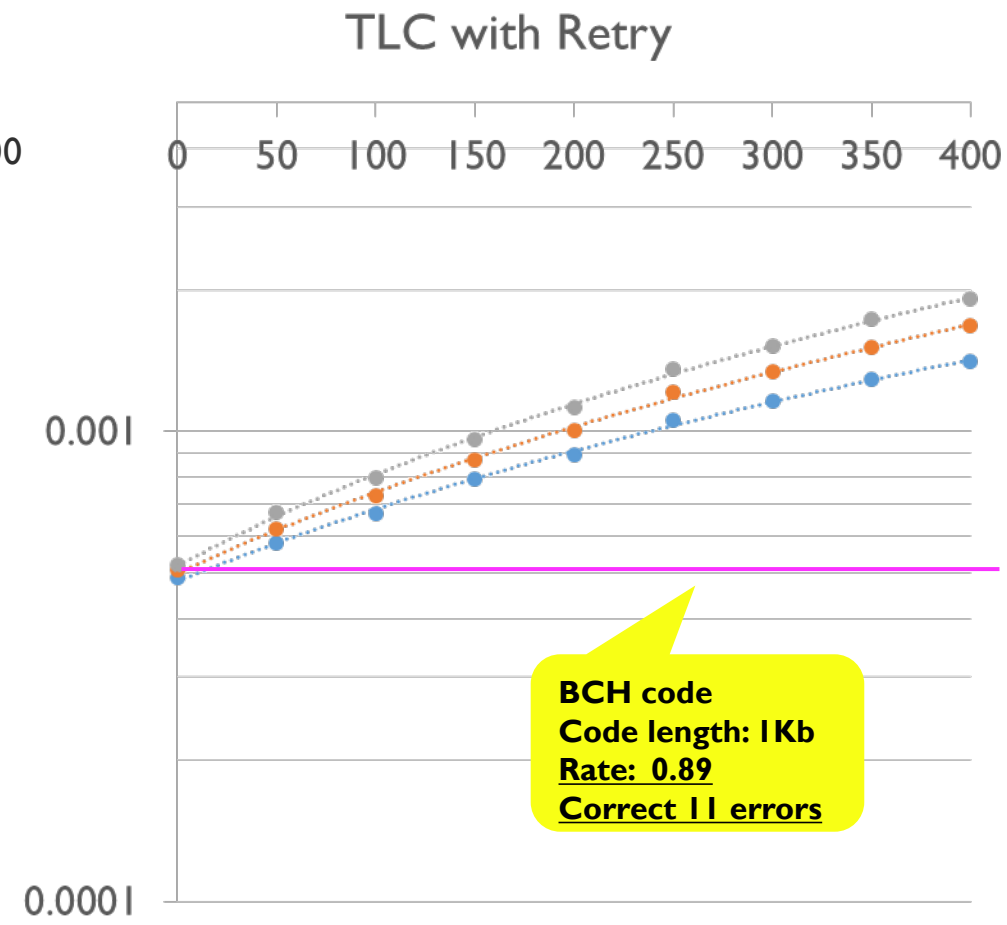
25.5 years

2x

12.5 years

Comparison based on Same Coding Redundancy (2)





12.7 years

10x

1.2 years

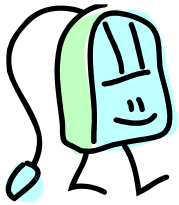
Summary

- Rank modulation can be implemented
  - in software using read-retry of the current NAND
  - (more efficiently) by slightly revising the current NAND architecture [3]

[3] Y. Li *et al.*, "Implementing rank modulation," NVMW 2015.

- Rank modulation provides
  - Significantly lower error rates in low P/E cycle region
  - Significantly longer (e.g. 10x more) data retention time for archival storage

- Rank modulation has been tested on the chips of various vendors
  - 1x and 2x nm MLC
  - 1y nm TLC



THANK YOU

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