This paper describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the paper do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

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STT-MRAM For Radiation Hard Environments

Sanjeev Aggarwal

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Everspin: MRAM Technology Pioneer

Everspin is a Leading Provider of Non-volatile Memory Technology and Products to Mission-Critical **Data Center**, **Industrial** and **Auto/Transportation** Applications

- Origins in Motorola/Freescale
- Independent since 2008
- Publicly traded : MRAM
- Long-served tier-1 customers

600+
Customers across many markets

110M+
Units shipped

600+
Patents and applications WW

Our products bring the unique benefits of MRAM to our customers where Performance, Persistence, Endurance and Reliability are critical

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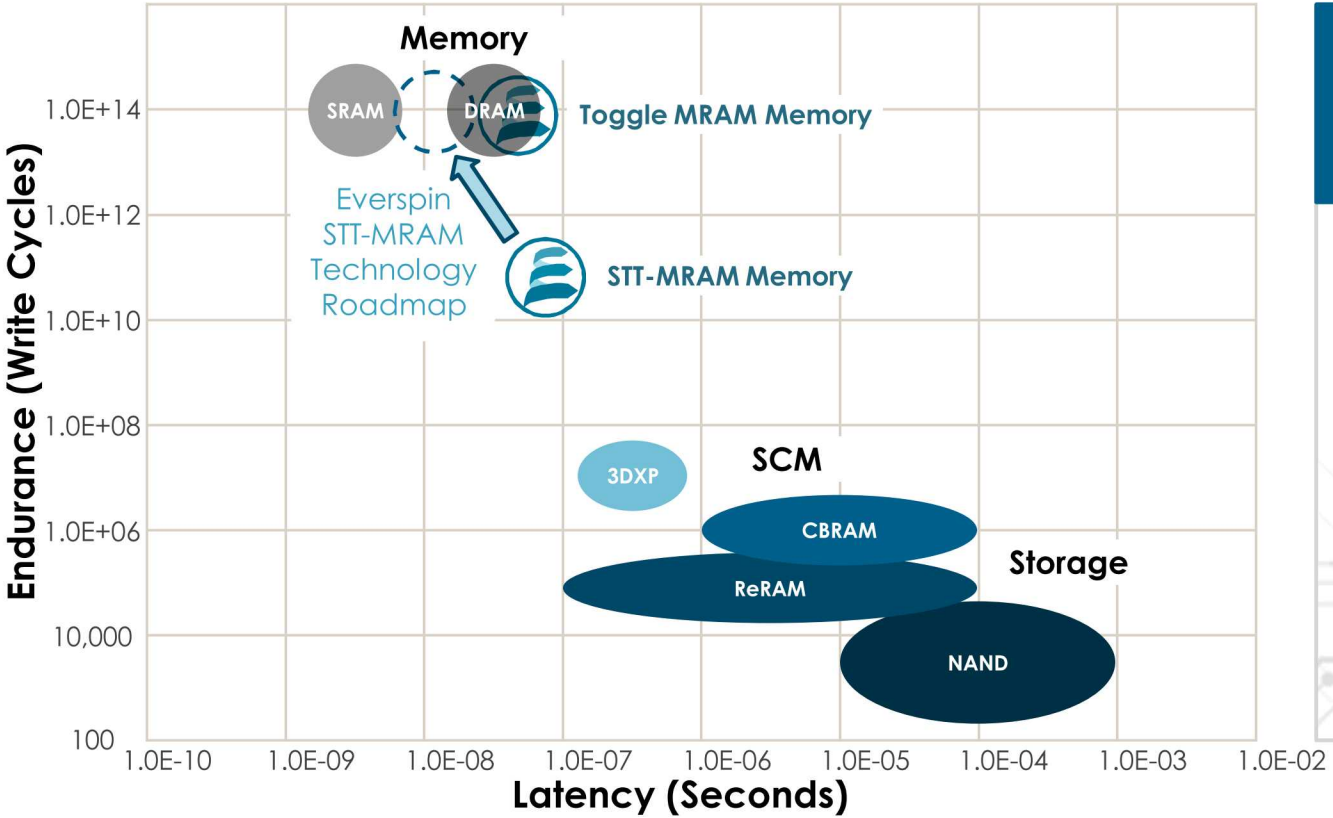
MRAM Brings Native Persistence to Memory Workloads



MRAM COMBINES PERFORMANCE OF MEMORY WITH PERSISTENCE OF STORAGE

- **Non-Volatile:** Maintains data without power or refresh
- **Fast:** Read/write similar to DRAM
- **Endurance:** Handles memory workloads

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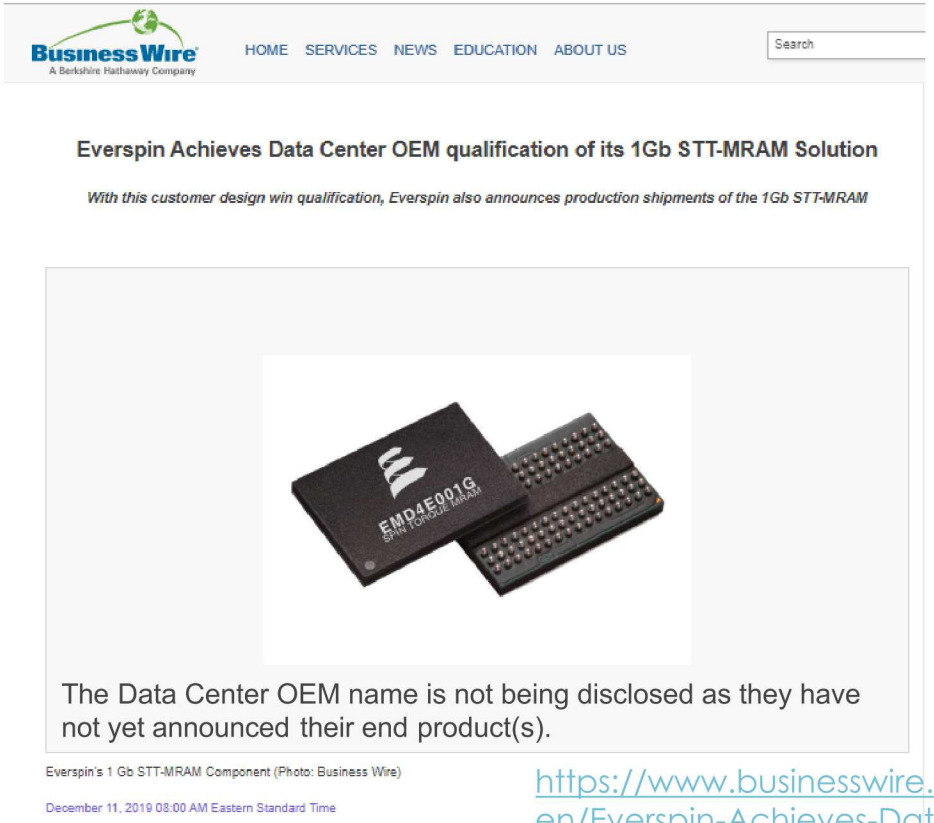
Data Center OEM Qualifies Everspin's 1Gb STT-MRAM Solution



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Everspin Achieves Data Center OEM qualification of its 1Gb STT-MRAM Solution

With this customer design win qualification, Everspin also announces production shipments of the 1Gb STT-MRAM

The Data Center OEM name is not being disclosed as they have not yet announced their end product(s).

Everspin's 1 Gb STT-MRAM Component (Photo: Business Wire)

December 11, 2019 08:00 AM Eastern Standard Time

https://www.businesswire.com/news/home/20191211005184/en/Everspin-Achieves-Data-Center-OEM-qualification-1Gb

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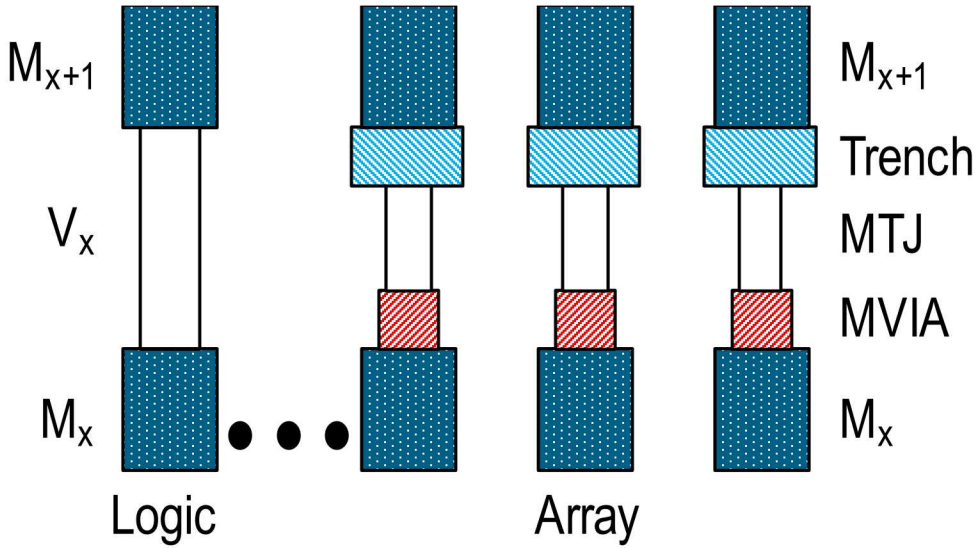
STT-MRAM – Easy to Integrate with Standard CMOS

On Axis Integration, 1Gb



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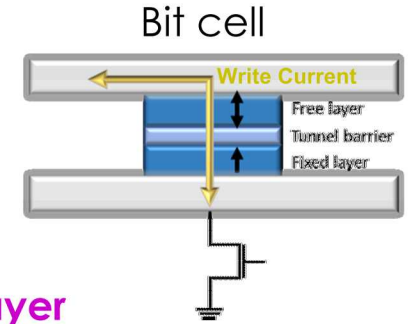
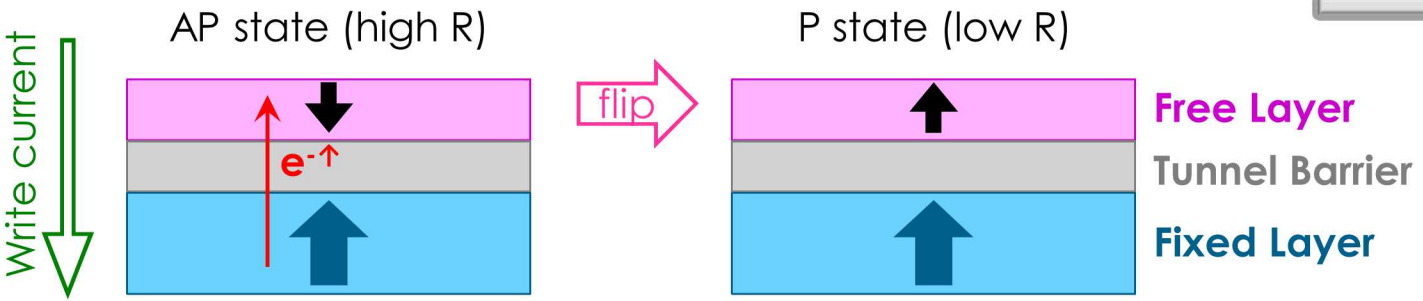
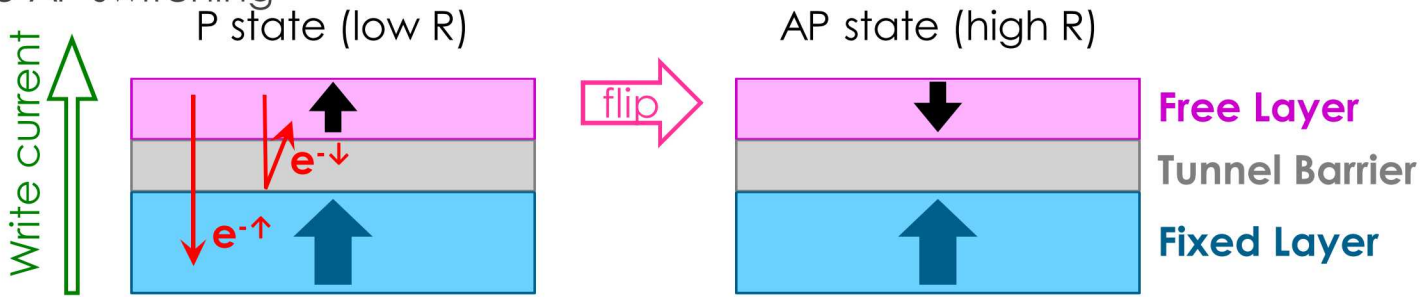
Spin-Transfer Torque (STT) Switching



- AP to P switching



- P to AP switching



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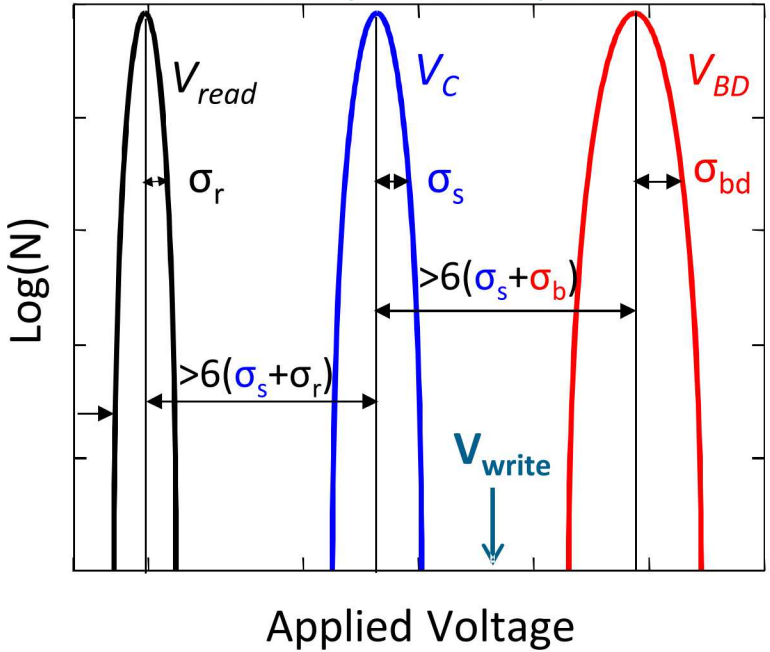
Must separate bit-to-bit distributions in the array

Separation of distributions is key for working memory

MB memory ⇒ >12σ separation



- Separation of V_C & V_{BD}
  - V_{write} must be well above V_C and well below V_{BD}
  - Tight switching distributions
  - Tunnel barrier reliability
- Separation of V_{read} & V_C
  - Avoid read-disturb errors
  - Bigger issue for smaller bits, lower I_C
- Separation gets worse with:
  - Shorter write pulses
  - Smaller bits
  - Extrinsic switching or breakdown behavior

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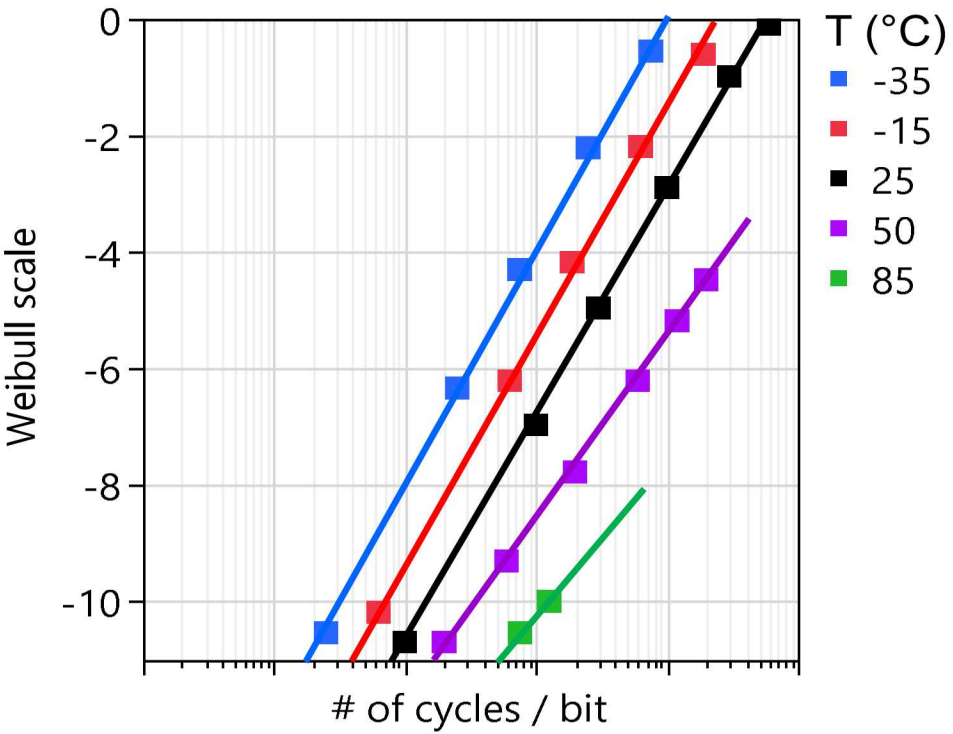
1Gb STT-MRAM Endurance across Temperature



- TDDB BER with ECC off vs. cycles shows linear breakdown distributions from -35°C to 85°C
  - Weibull plot at different temperature are horizontally offset for clarity
- No indication of a deviation due to early breakdown of extrinsic defect bit observed
- The TDDB beta parameter is relatively similar across the temperature range

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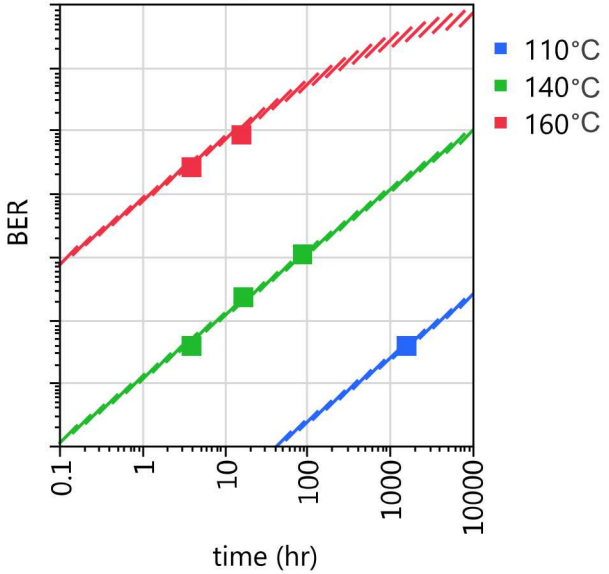
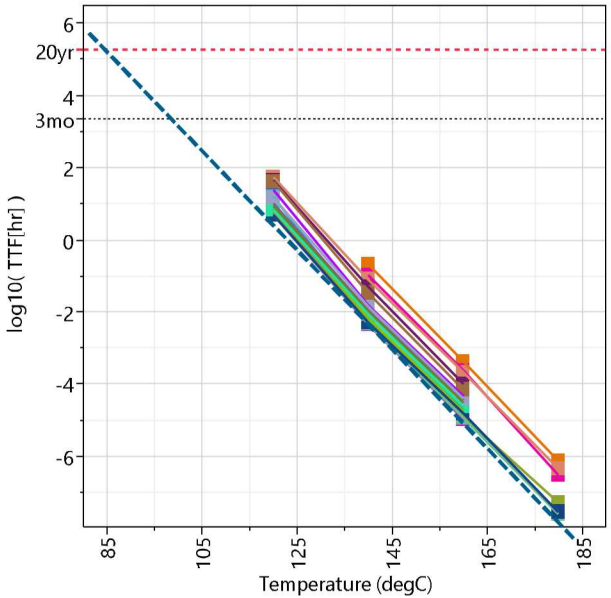
Extended Temperature Range: Data retention for 1Gb STT-MRAM

Example die



Projected Data Retention



- Baked typical die over 110 – 160 °C for 1hr to 9 weeks
- Fitted to project data retention; Time-to-failure (TTF) is extracted from the fit

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STT-MRAM Radiation Hard Testing

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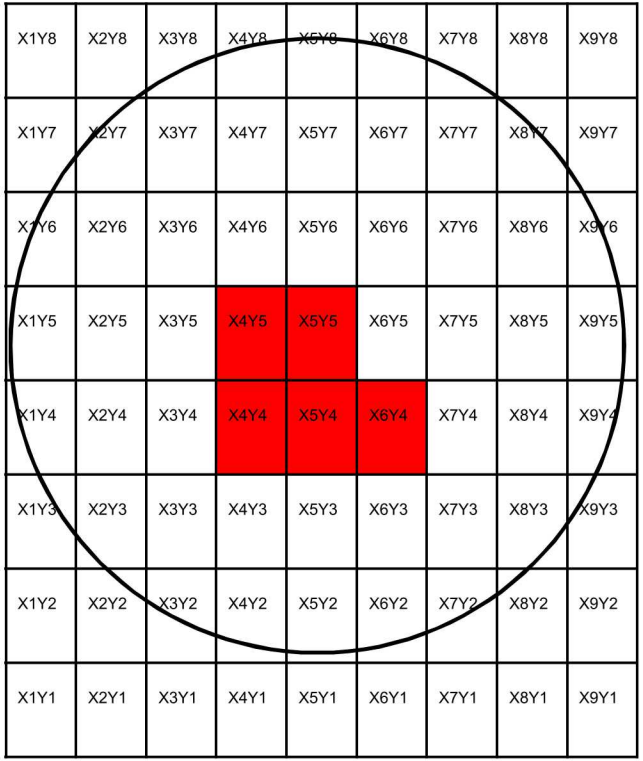
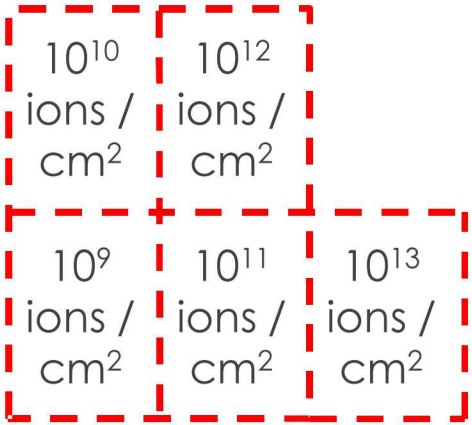
Heavy Ion Exposure Map

- MTJs have metallic top/bottom electrodes, but no CMOS transistors
- 5 reticle shots at wafer center exposed to heavy ions
- Doses varied from 10^9 to 10^{13} ions/cm^2
- Remaining reticle shots served as unexposed control MTJs



5 exposed reticle shots



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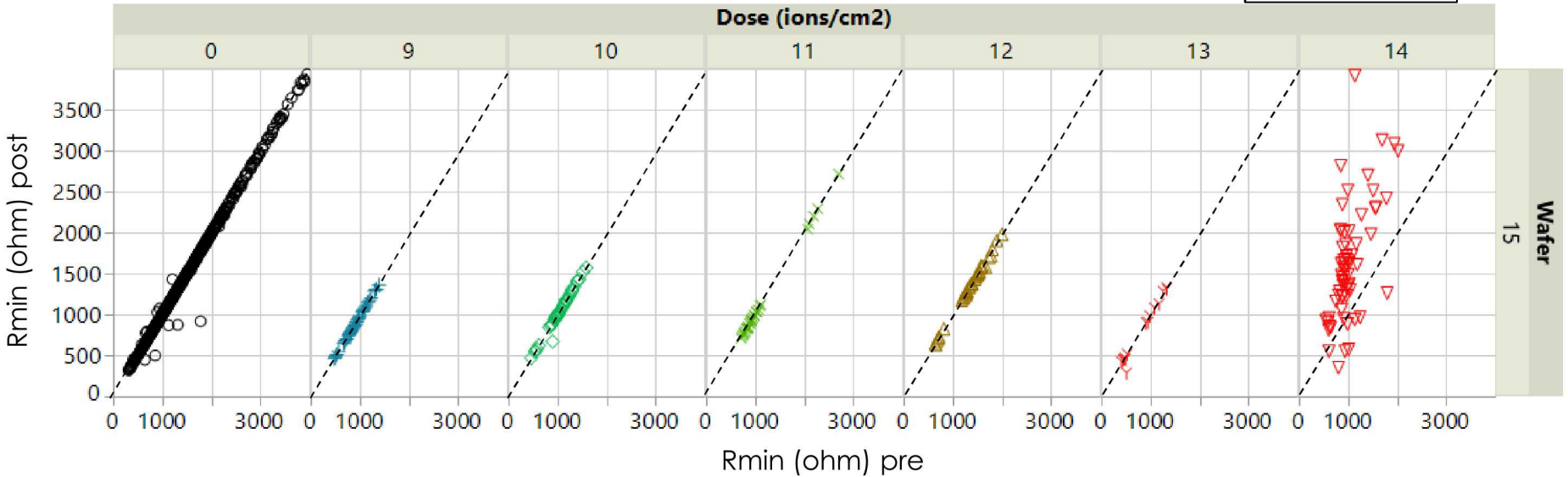
Rmin: Post vs. Pre-Exposure (Single MTJ Structures)

Short flow
1 point = 1 bit



- Exact same MTJs were measured after exposure (y-axis) vs. before exposure (x-axis)
- Increasing dose is plotted left to right starting at dose = 0 (unexposed reticle shots)
- Rmin remains unchanged by exposure up to 10^{13} ions/cm^2
  - However, 10^{13} ions/cm^2 shows significant magnetic change to MTJ: See next slides

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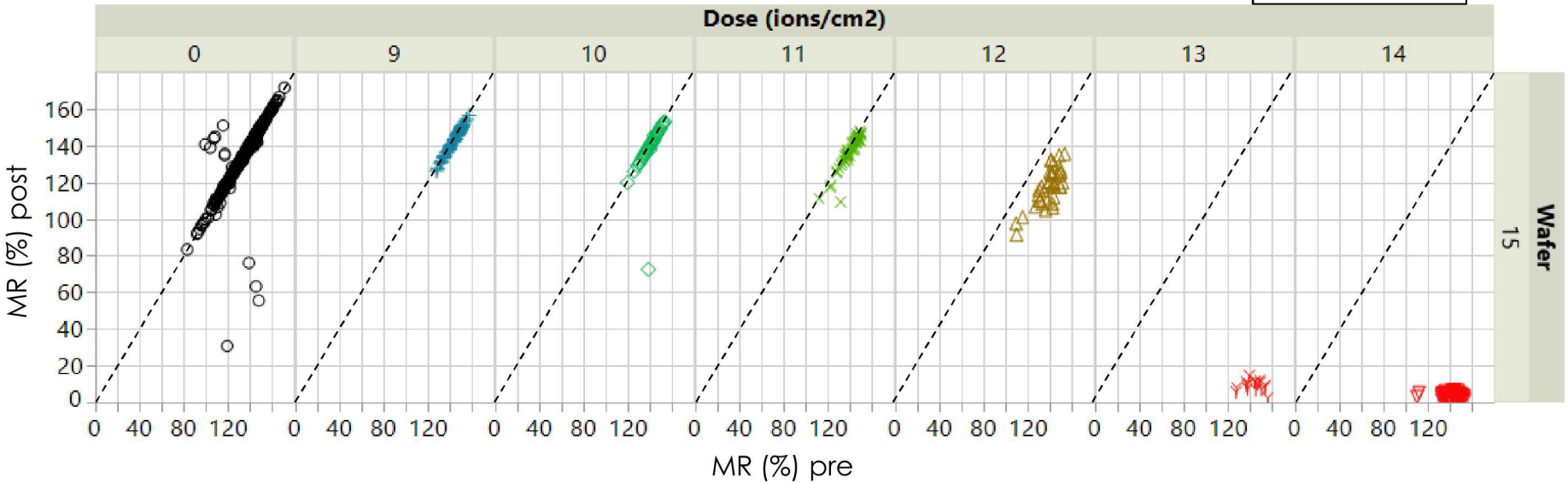
MR: Post vs. Pre-Exposure (Single MTJ Structures)

Short flow
1 point = 1 bit



- MR is almost unchanged by exposure up to 10^{11} ions/cm^2
- Mild MR decrease at 10^{12} ions/cm^2 indicates some effect
- Loss of MR at 10^{13} – 10^{14} ions/cm^2 indicates more significant damage

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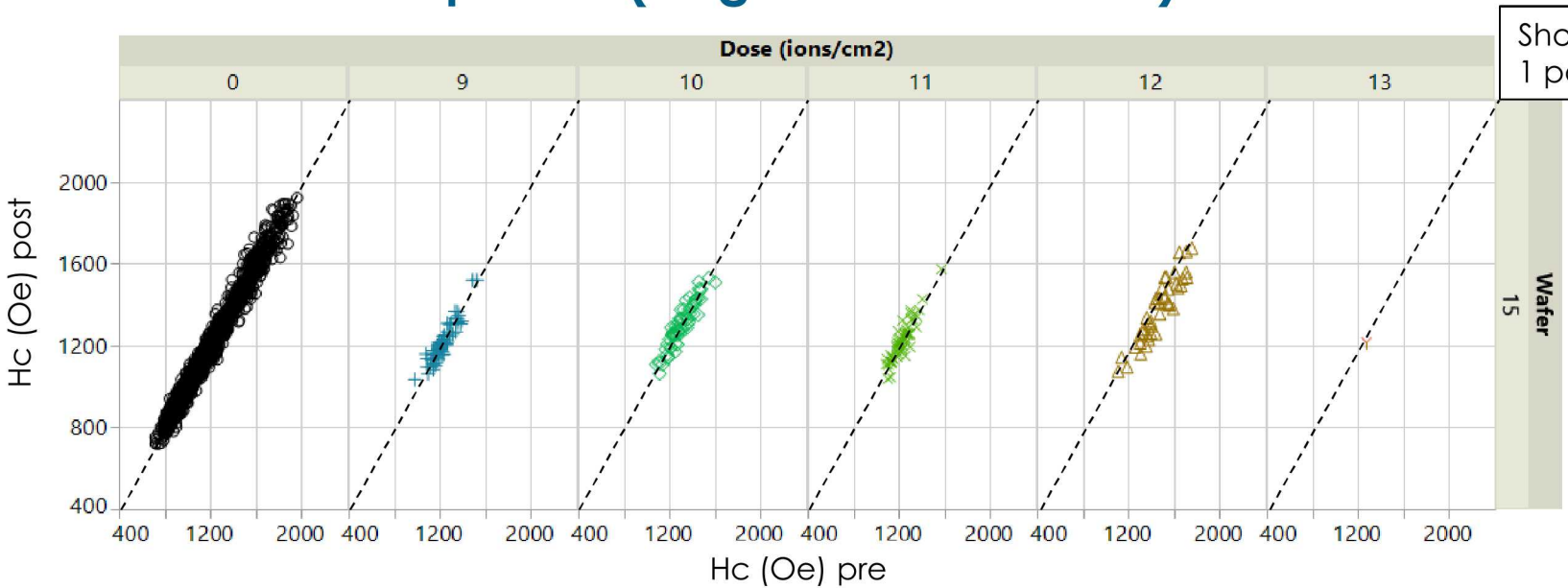
Hc: Post vs. Pre-Exposure (Single MTJ Structures)



- Hc is unchanged by exposure up to 10^{11} ions/cm^2
- Mild Hc decrease at 10^{12} ions/cm^2 indicates some effect
- No data plotted at 10^{13} – 10^{14} ions/cm^2 because they have no MR so Hc cannot be defined
- Hc-correlation plots are noisier than for Rmin and MR due to thermal-activated, random switching in MTJs: This is inherent to MTJs and seen also at dose = 0

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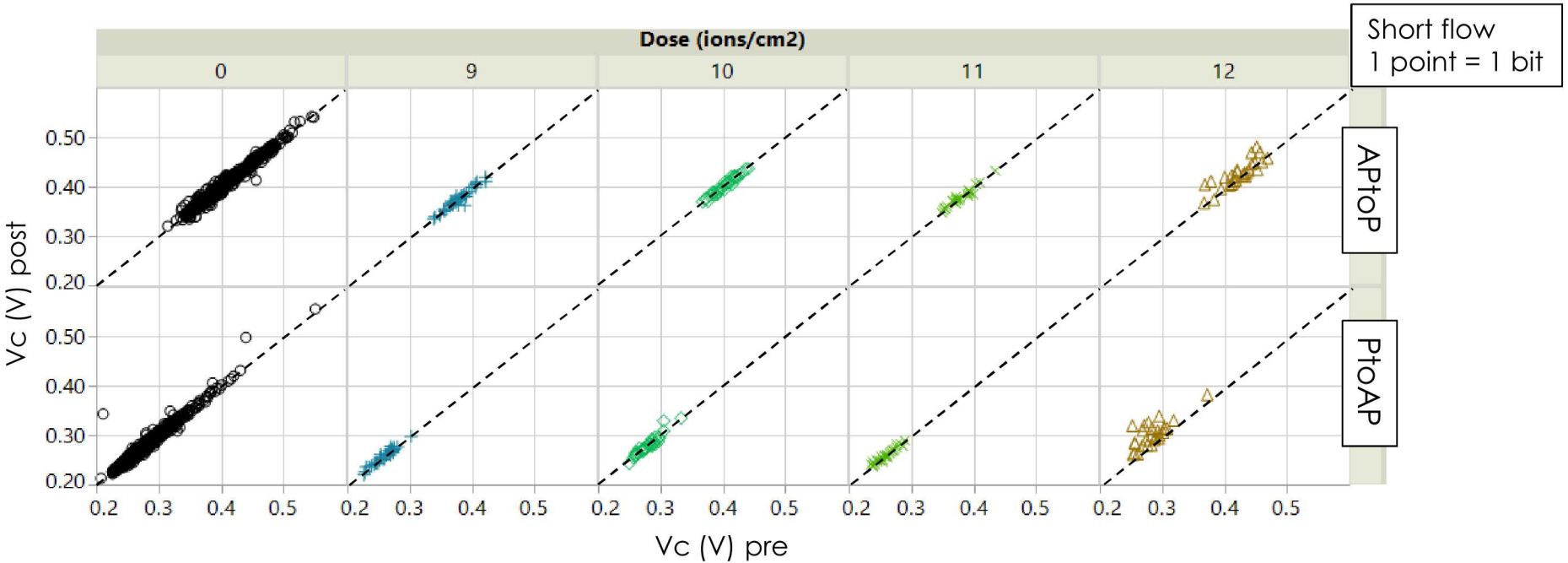
Vc: Post vs. Pre-Exposure (Single MTJ Structures)



- Vc is unchanged by exposure up to 10^{11} ions/cm^2
- 10^{12} ions/cm^2: Slight increase in magnitude and spread of Vc
- No data plotted at 10^{13} – 10^{14} ions/cm^2 because they have no MR, so Vc cannot be defined

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Summary

- Everspin has successfully transitioned STT-MRAM from R&D to volume manufacturing
  - 256Mb and 1Gb in production at Everspin
  - R&D roadmap to higher densities planned

- Examined magnetic field and spin torque voltage switching before/after heavy ion exposure
  - Negligible changes up to dose of 10^{12} ions/cm^2
  - 10^{13}-10^{14} ions/cm^2 significantly affect MTJ behavior

- No significant change after exposure up to dose of 10^{12} ions/cm^2 for:
  - Magnetic-field switching: Rmin, MR, and Hc
  - Spin-torque voltage switching: Vc

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Thank you.