QLC Challenges

QLC SSD's Require Deep FTL Tuning
Karl Schuh – Micron

The Wonders of QLC

Flash Memory Summit

TLC

QLC
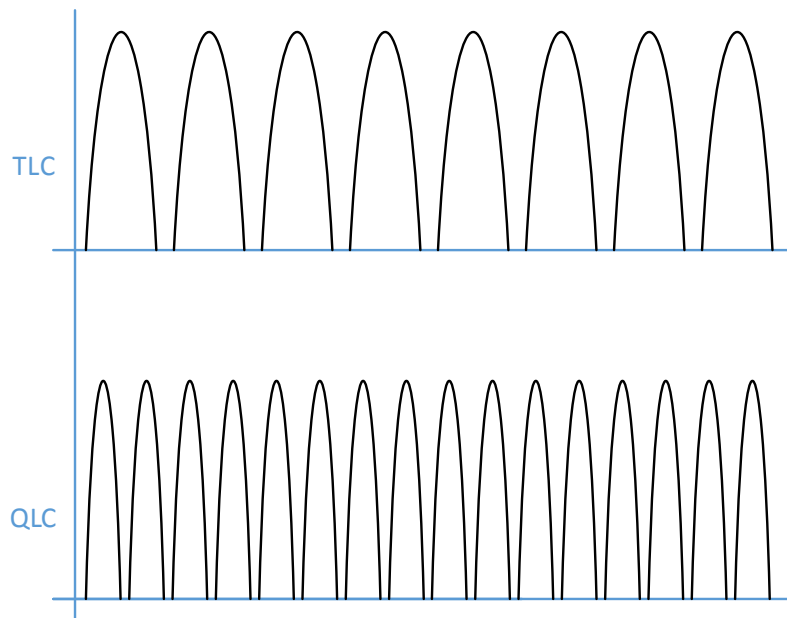
- Cost
- Capacity
- Performance
  - Error Rate depends upon compensation for transaction history
- Endurance
  - Data Organization is Key
  - Complex NAND Management algorithms required to support the target Total Bytes Written

Not 3 bits-per-cell to 4 bits-per-cell, but 8 charge levels to 16 charge levels!

Performance and Endurance
Inextricably interconnected in QLC

- **Data Organization and Steerage – driven by the workload**
  - SLC, MLC and TLC caching to filter high frequency data, and smooth throughput
  - Read / Write mix
  - Logical Saturation
  - Over-Write and Deallocation frequency
  - Steams aid in Data Separation

- **Write Throughput**
  - Careful attention to history and environment
  - NAND characterization

- **Read Latency**
  - Continuous Tuning
 - Complex algorithms based on transaction history and characterization

Data Organization
Traditional

FTL Tables

LUN 0   LUN 1   LUN 2   LUN 3

Read LBA → Physical Address

Write LBA → Physical Address
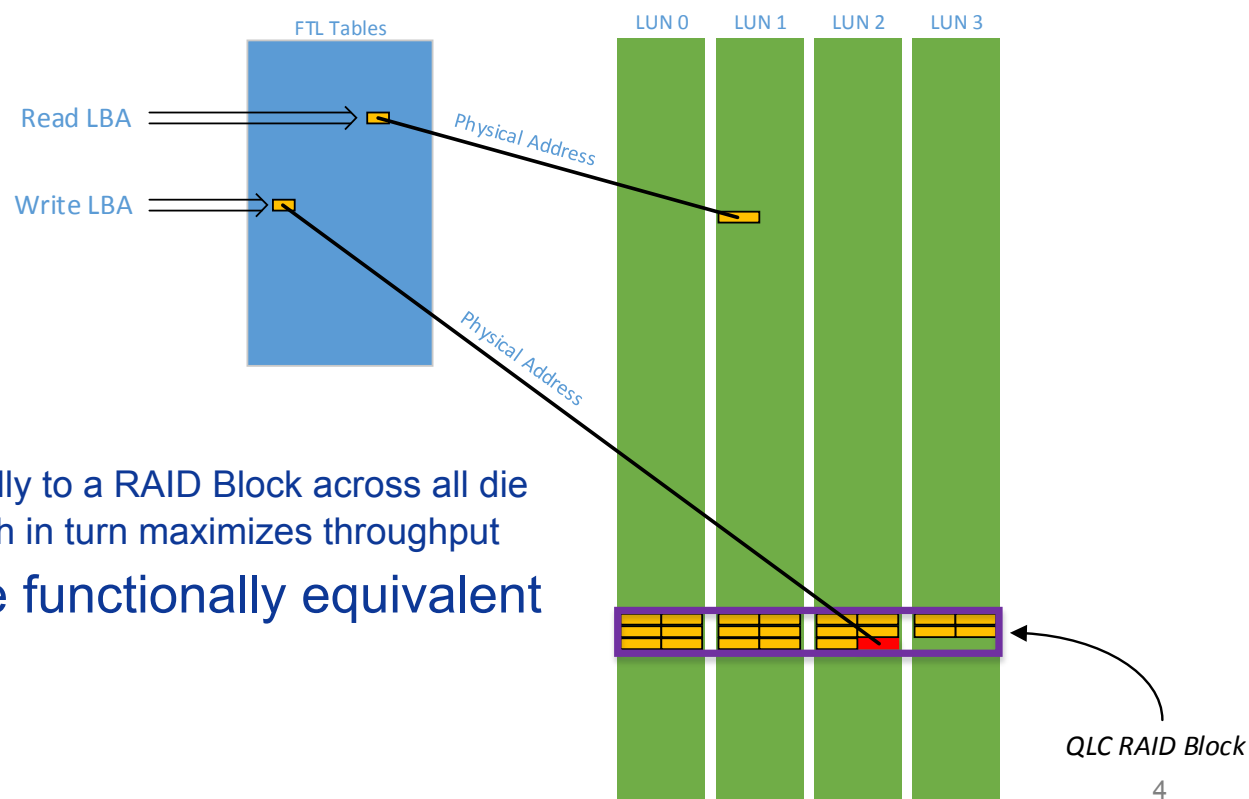
- **Flat FTL tables**
  - Direct lookup for Reads
  - Writes mapped sequentially to a RAID Block across all die
  - Maximize active die, which in turn maximizes throughput
- **Hierarchical tables are functionally equivalent**

QLC RAID Block

Intermediate Caching
Endurance and Burst Performance

FTL Tables

Write LBA

Recycling

LUN 0 LUN 1 LUN 2 LUN 3

SLC/MLC/TLC Cache Block
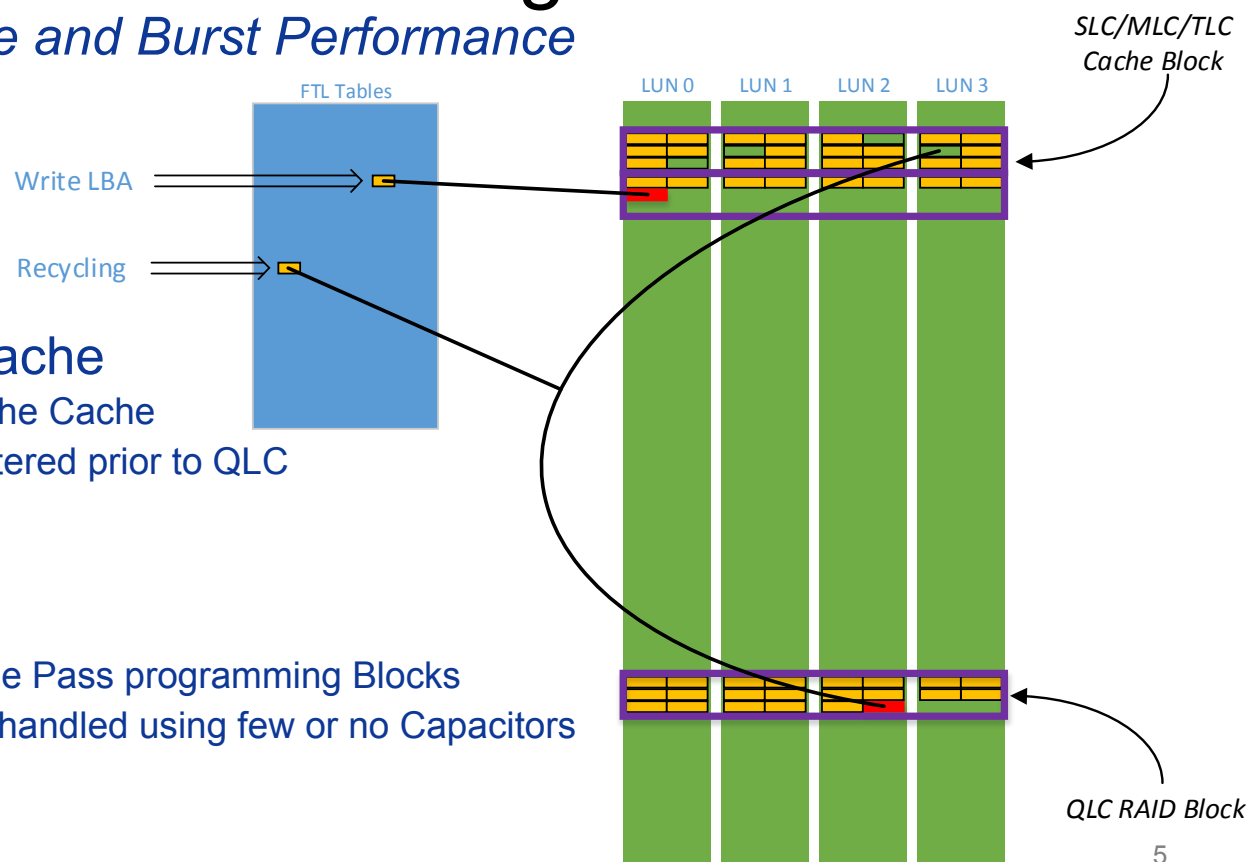
- ## SLC or MLC or TLC cache
  - Write bursts absorbed by the Cache
  - High frequency updates filtered prior to QLC
  - Low FUA latency
  - Improved Endurance
- ## Reliability
  - Host Writes stored in Single Pass programming Blocks
  - Asynchronous power loss handled using few or no Capacitors

QLC RAID Block

Dynamic Caching
Burst Performance

FTL Tables

LUN 0   LUN 1   LUN 2   LUN 3

Write LBA

Recycling

Dynamic Cache Allocation

QLC RAID Block
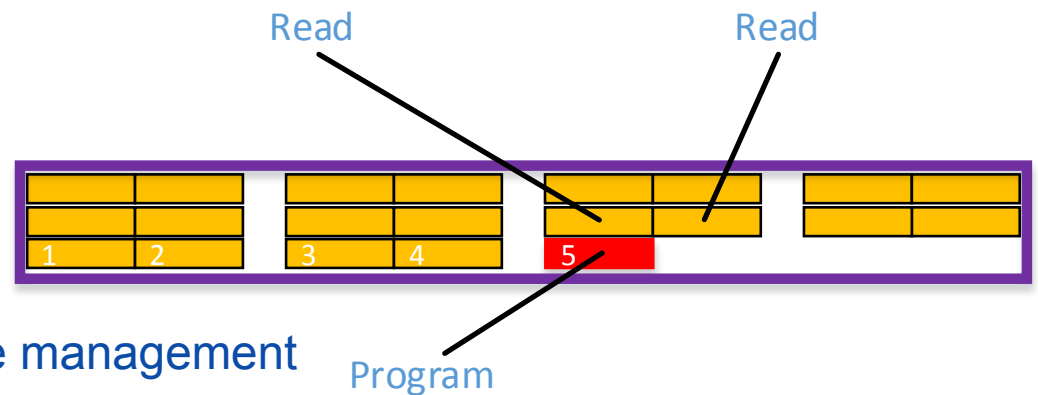
- **Host Burst Pattern**
  - Logical Saturation
  - Size of the Cache
  - Rate of Recycling
  - Transition from Caching to direct Write
  - Consistent Throughput
- **Endurance**
  - Wear Management
 - SLC / MLC / TLC vs. QLC Wear Ratio
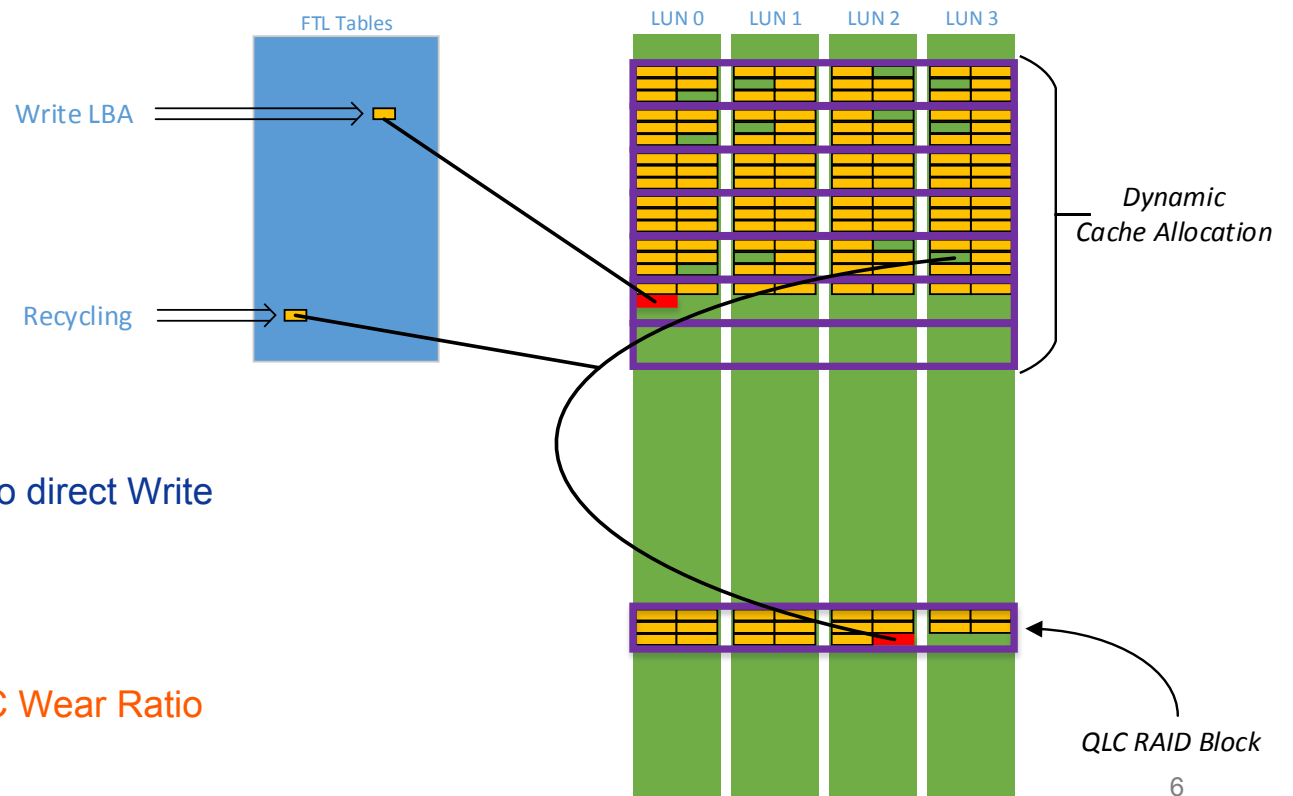
Write Throughput
Active Management

Read   Read

Program

- QLC Programming requires active management
- Tuning required for partially written Blocks
  - Erase History
  - Read History
  - Program Tuning
- Traditionally we leverage relationships between physical Blocks and Pages

Write Throughput
Subdivision of Media

FTL Tables

LUN 0   LUN 1   LUN 2   LUN 3
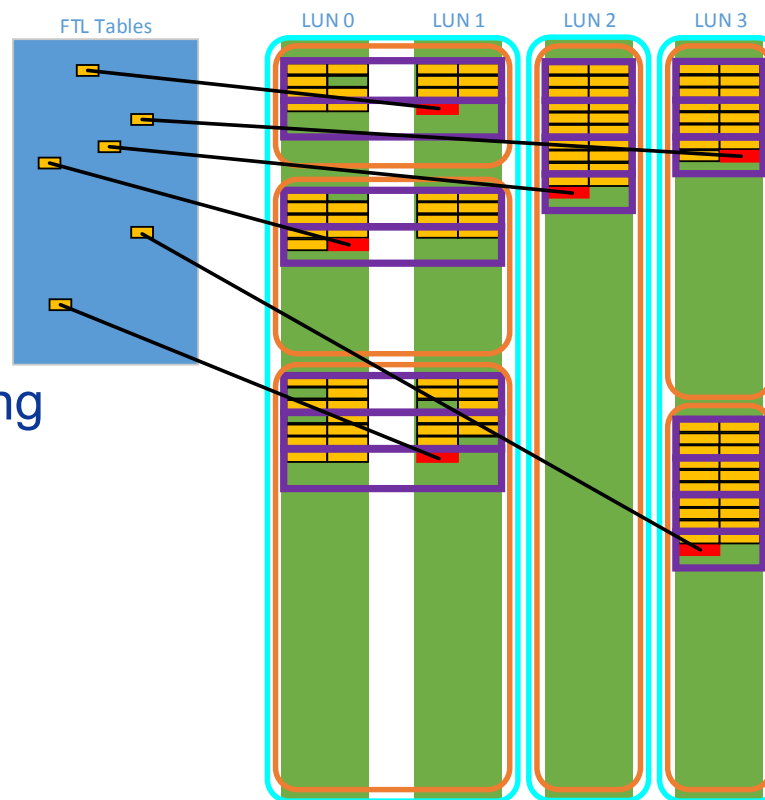
- Physical Organization of Blocks becoming increasingly complex

  - Fewer LUNs
  - Endurance Sets
  - Namespaces
  - Streams

Write Throughput

FTL Tables   LUN 0   LUN 1   LUN 2   LUN 3

- Don't forget about Recycling
  - Doubles the number of active Blocks

As Physical Data Layout complexity increases,
We can no longer leverage Block to Block relationships
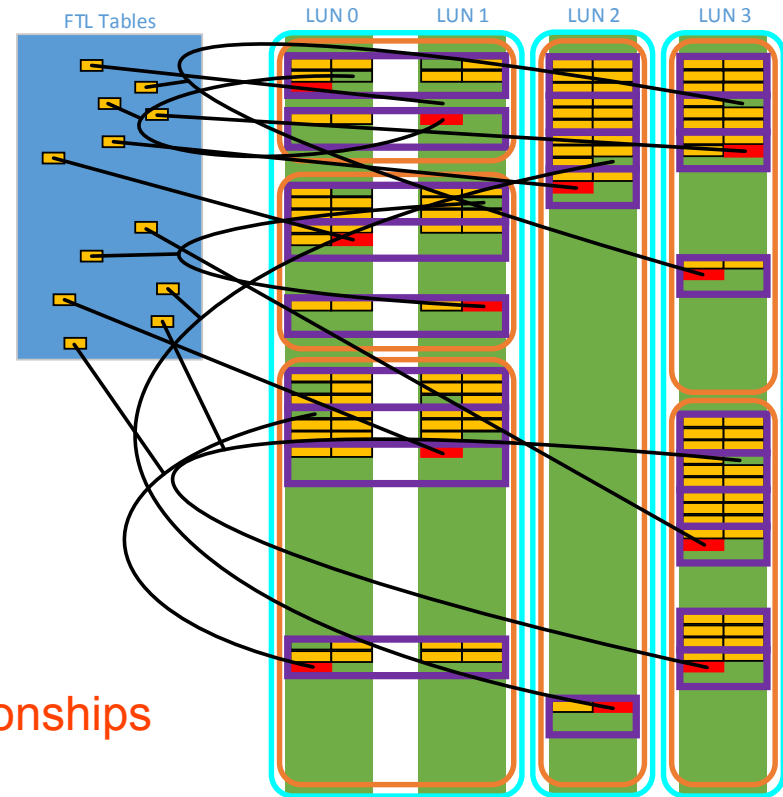
Read Latency
Minimal and Consistent

- **Die Characteristics**
- **Block History**
  - Erase Count, and Time
- **Page History**
  - Read Frequency
  - Adjacent Page operations
  - When and at what temperature data was written
- **Significant Tuning Data Available**
  - Pre and Post Computation / Organization
  - At a fine granularity
  - Accessed and updated Every IOP

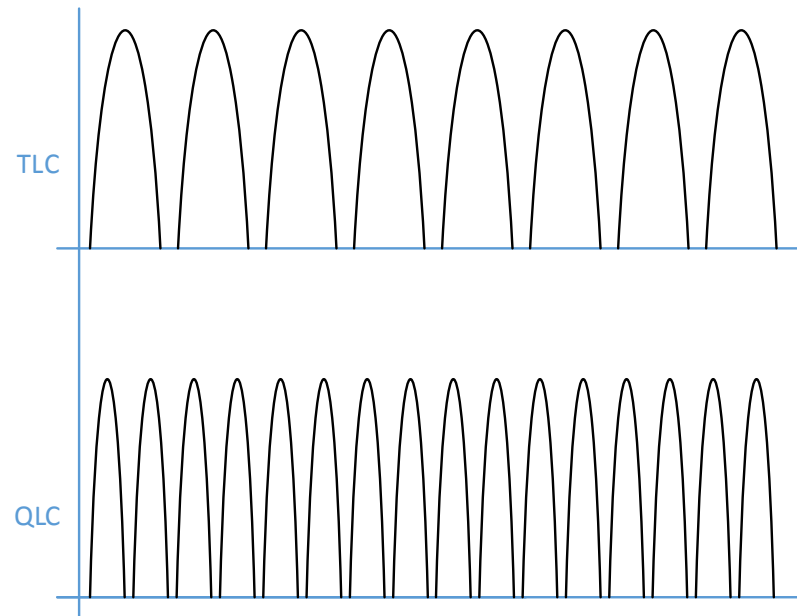### Manage the Trigger Rate

Continuous Read Tuning
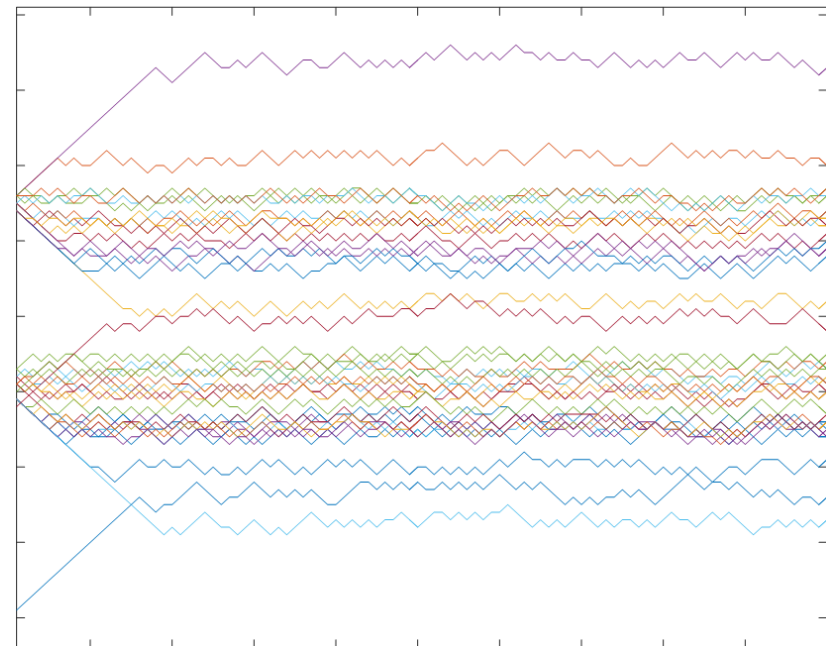
Summary

- **Challenges and Efforts**
  - Significant Logical and Physical data tracking
  - Continuous Tuning and Adjustment
  - Directed and Aligned NAND characterization

- Endurance
- Write Throughput
- Read Latency / Consistency

TLC

QLC

QLC offers many options over TLC, but is <u>exponentially</u> more complex to manage.

Thank You!