Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

Implementing Concurrent Non-Event Transitions in CMS

In partnership with:

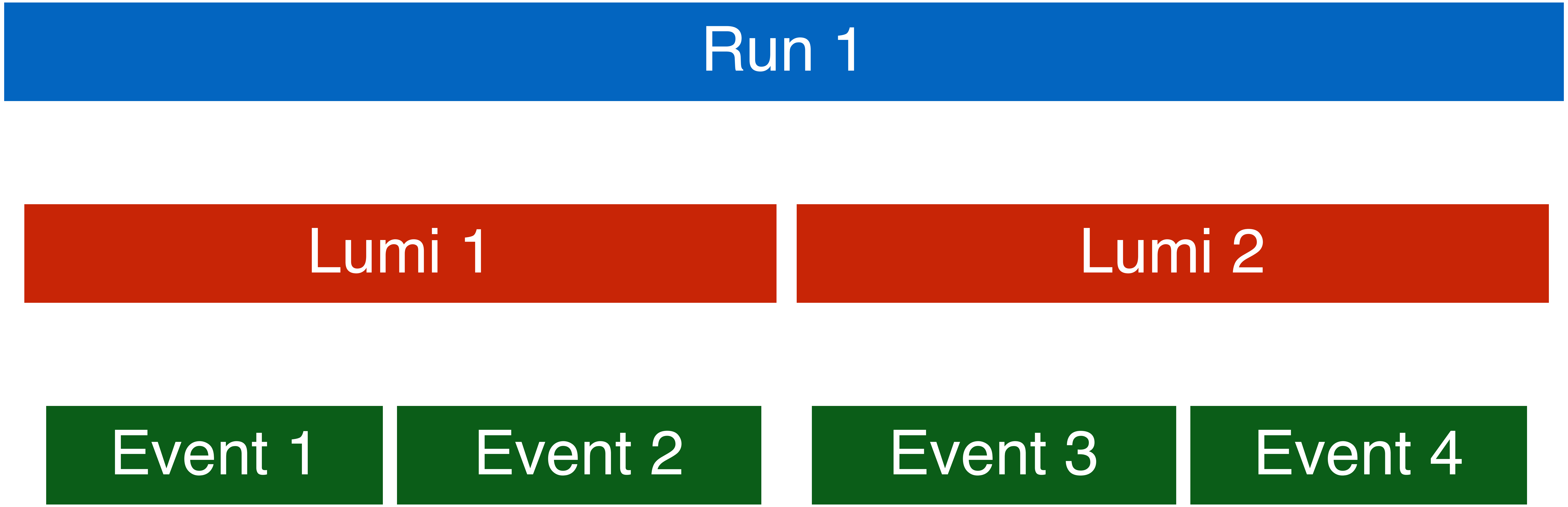
Context

- CMS uses a multi-threaded framework
  - Used in production since 2016
  - Built using Intel's Thread Building Block (TBB) task library

- Initially only supported
  - concurrent processing of events and
  - concurrent processing of modules within an event

- Goal: Allow all framework transitions to be processed concurrently

CMS Data Hierarchy



Run 1

Lumi 1

Lumi 2

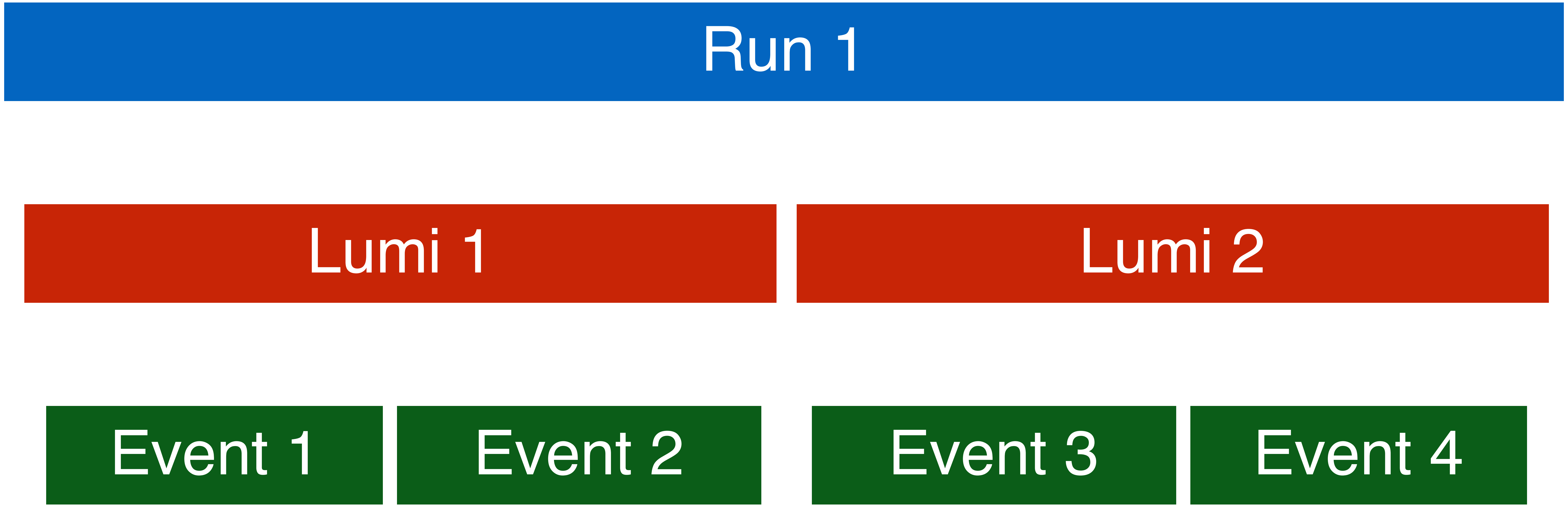
Event 1

Event 2

Event 3

Event 4

CMS Data Processing Transitions



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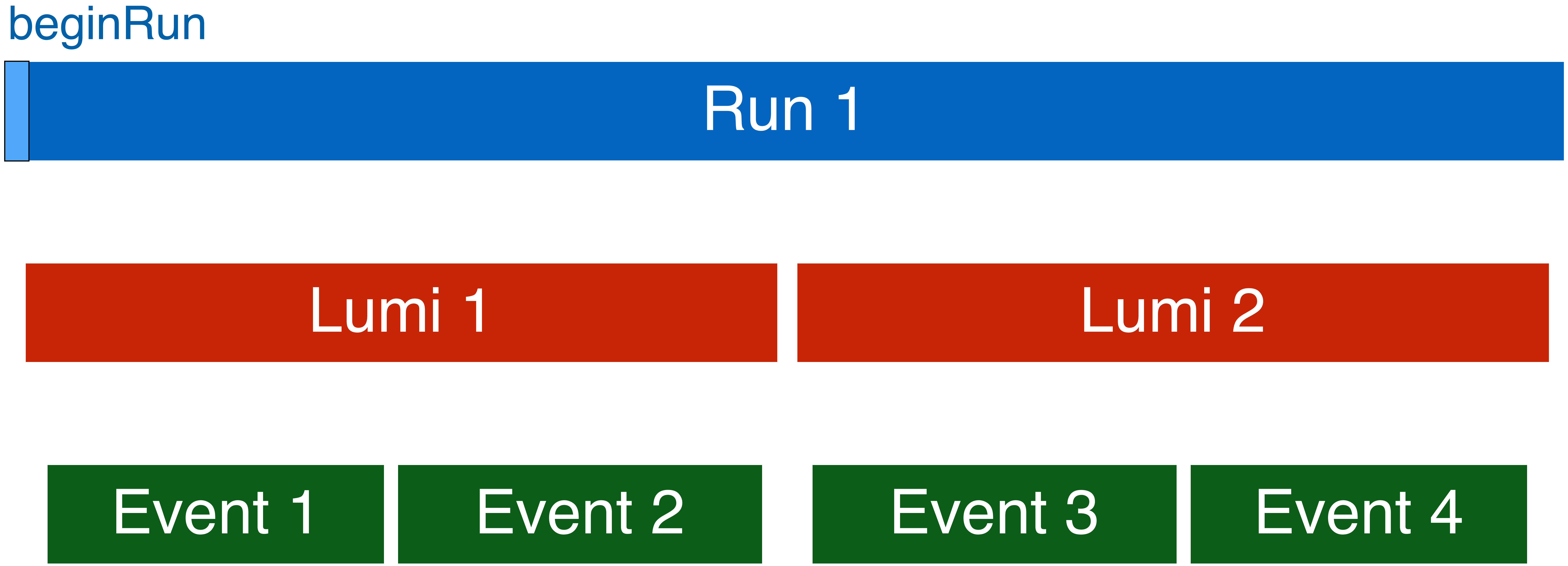

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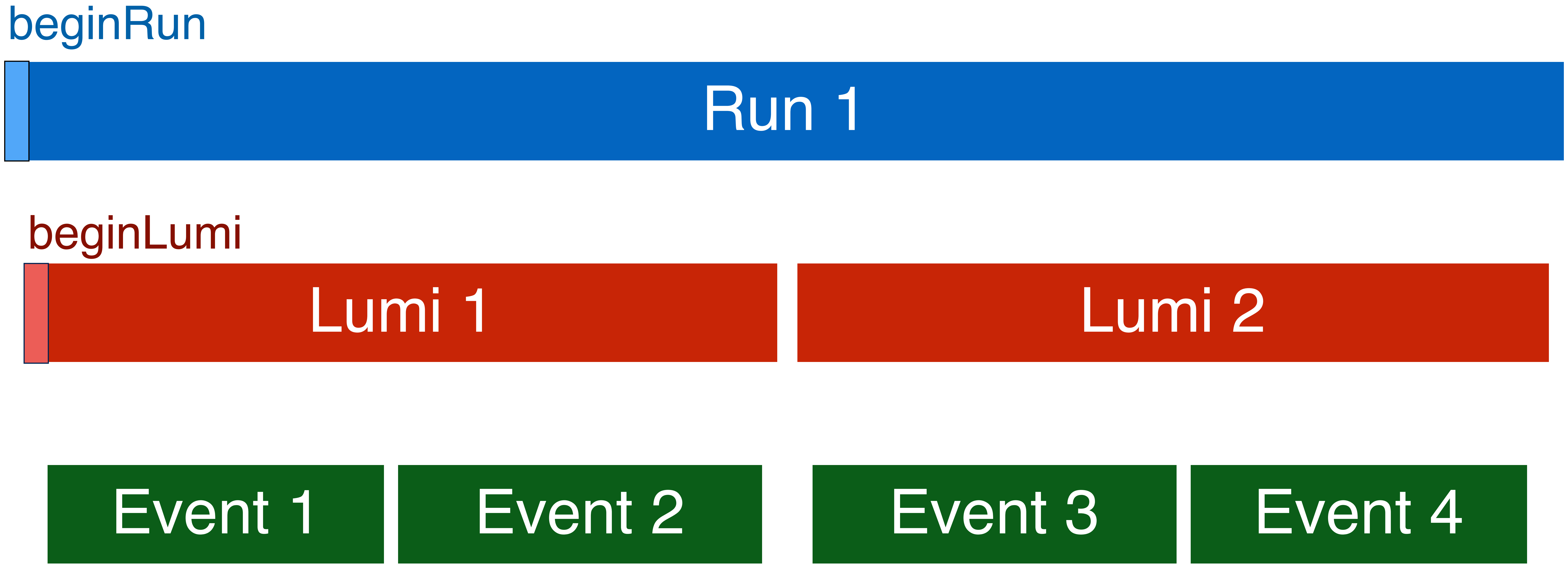

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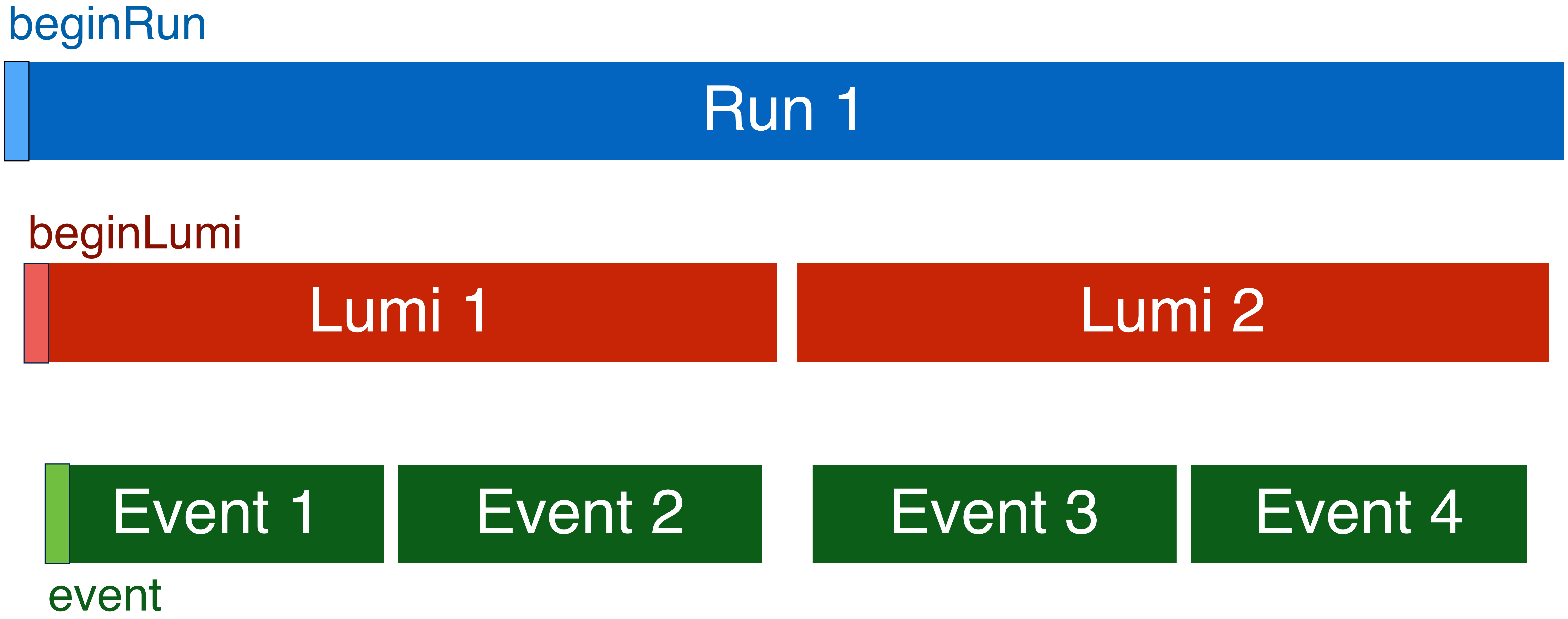

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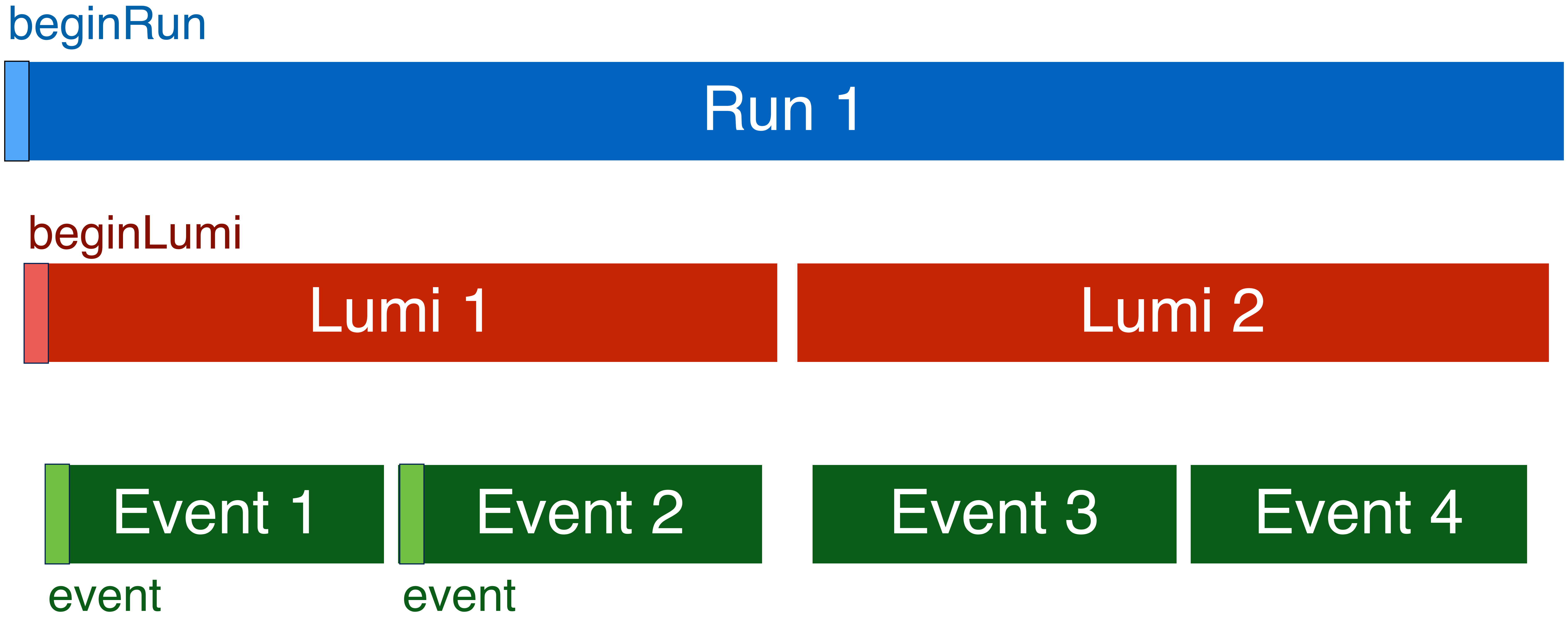

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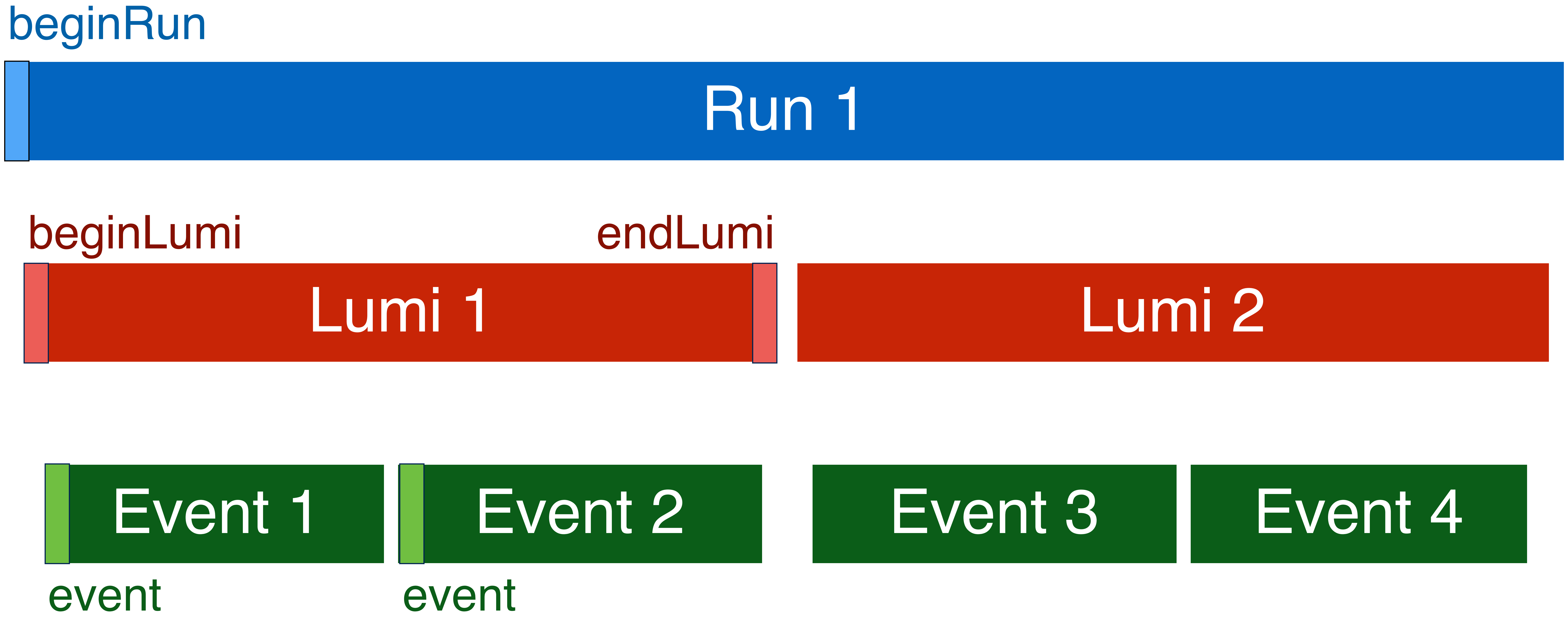

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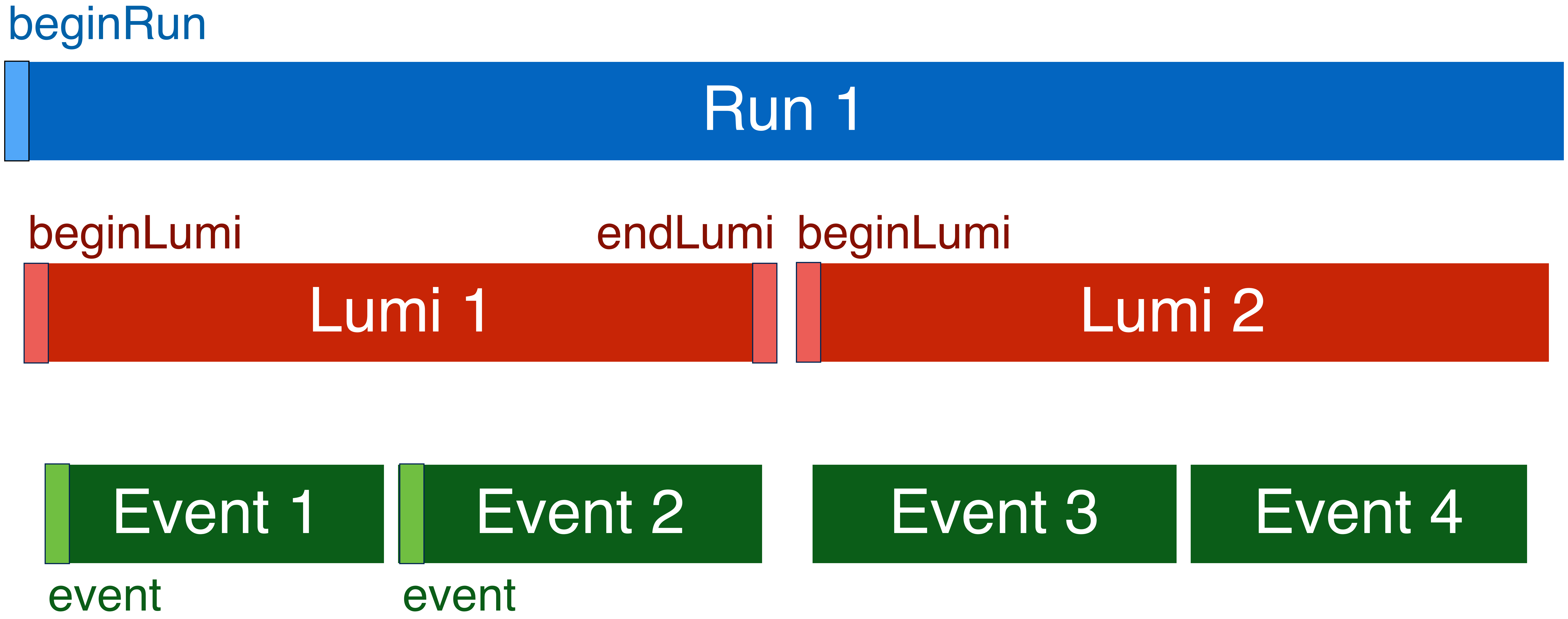

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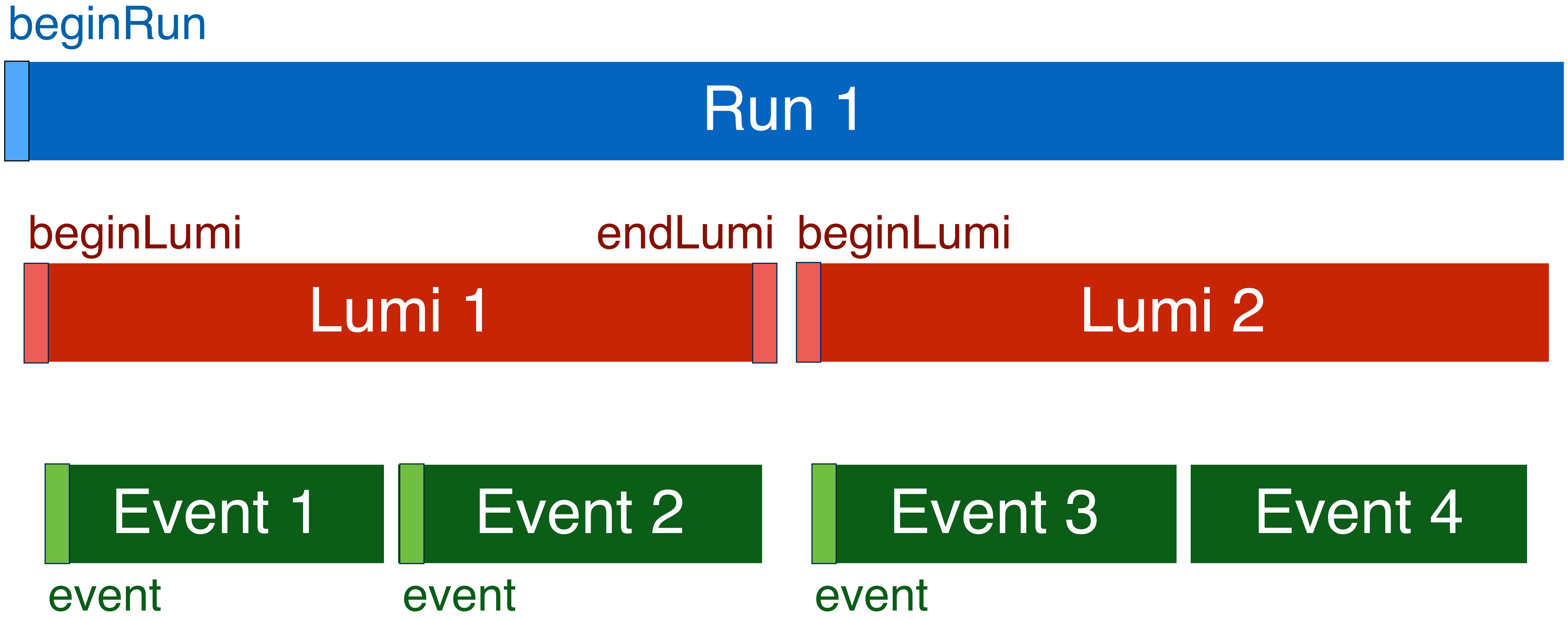

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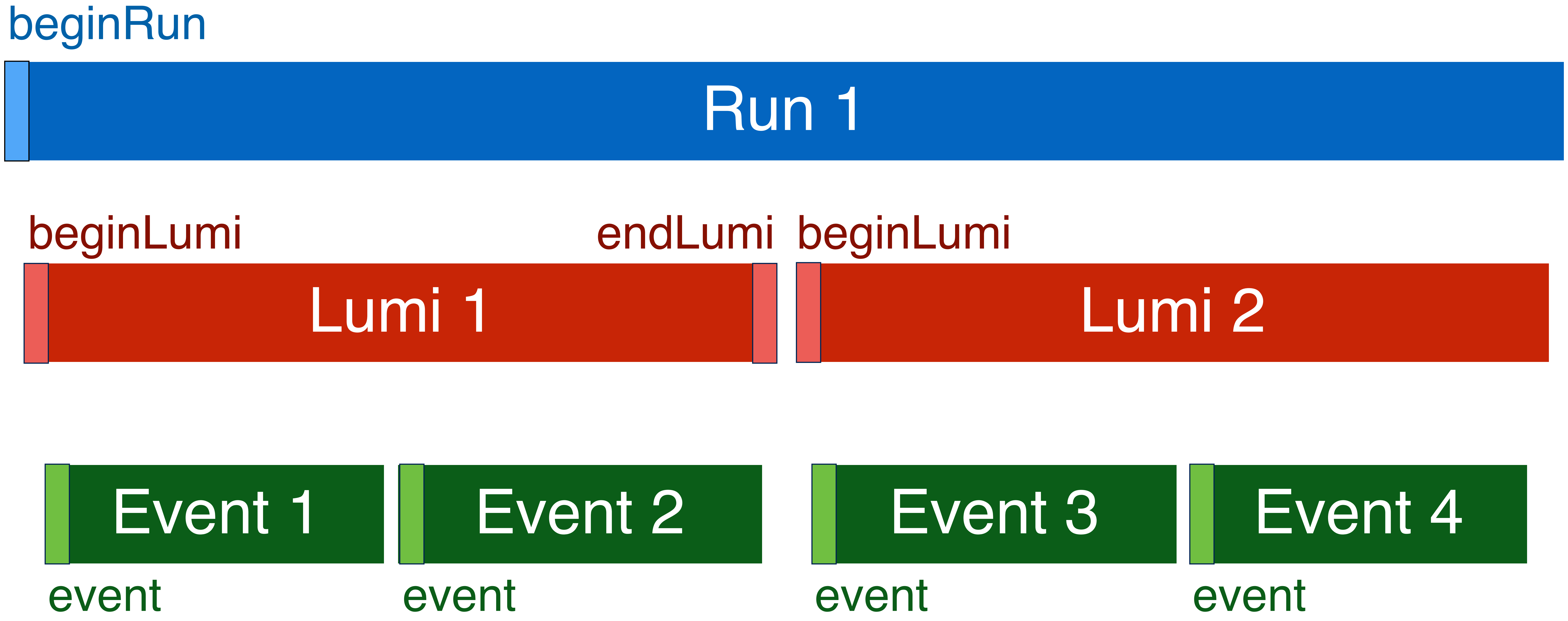

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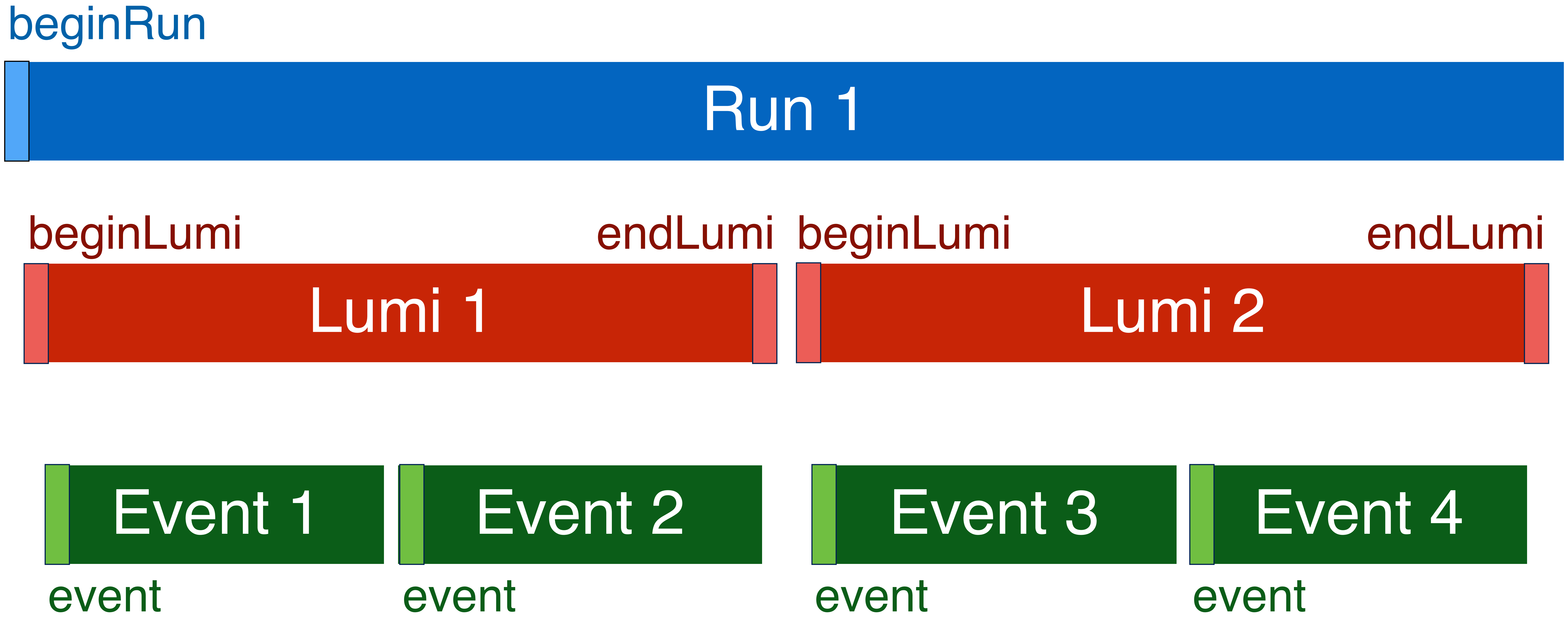

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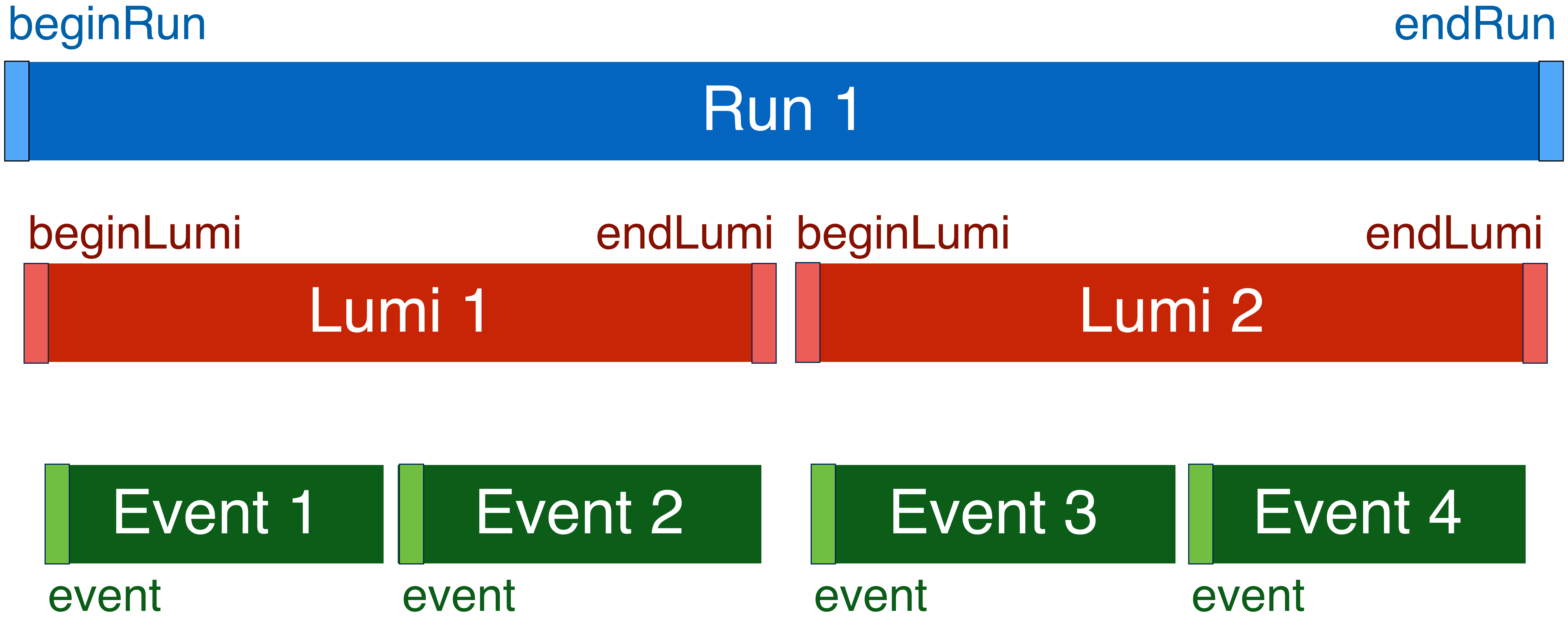
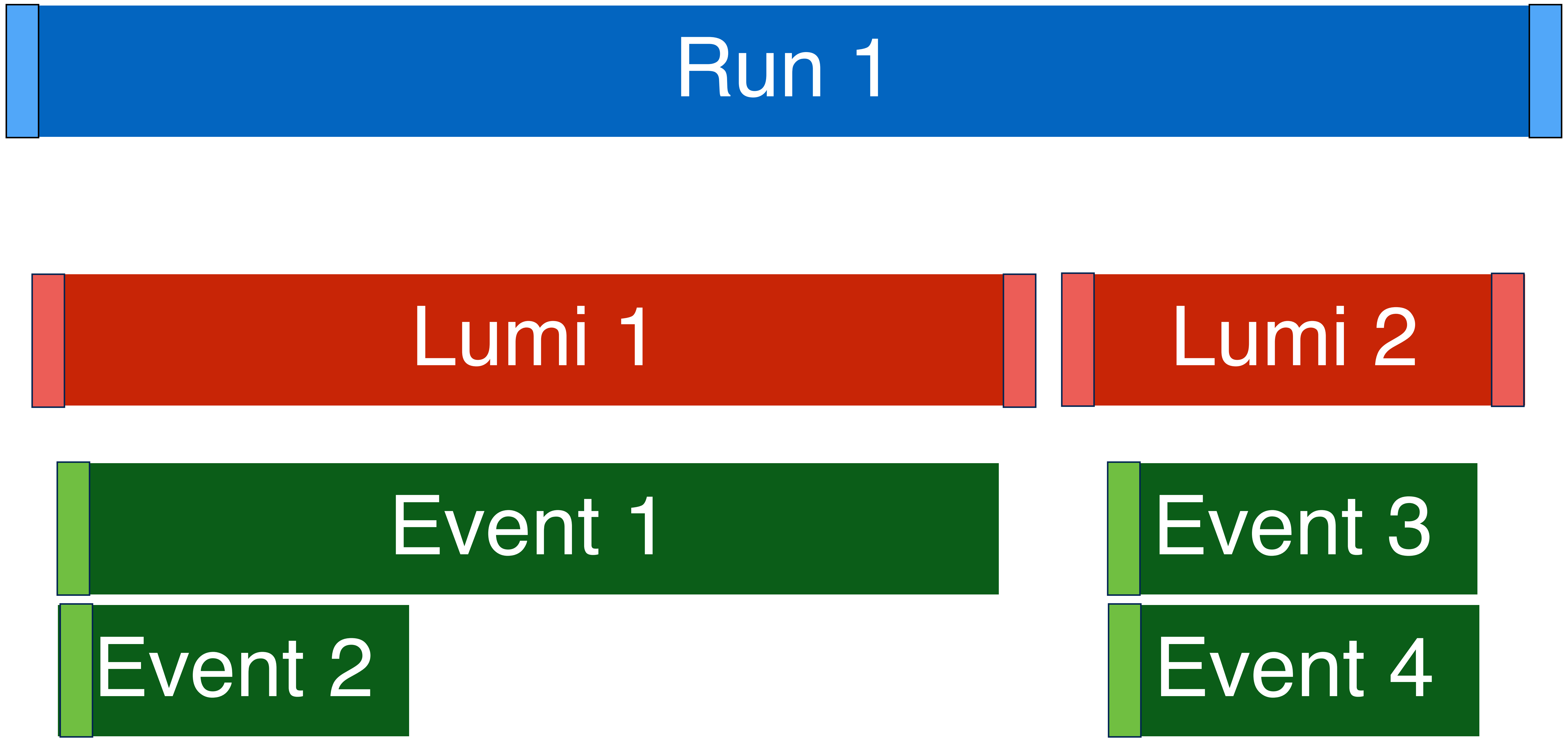
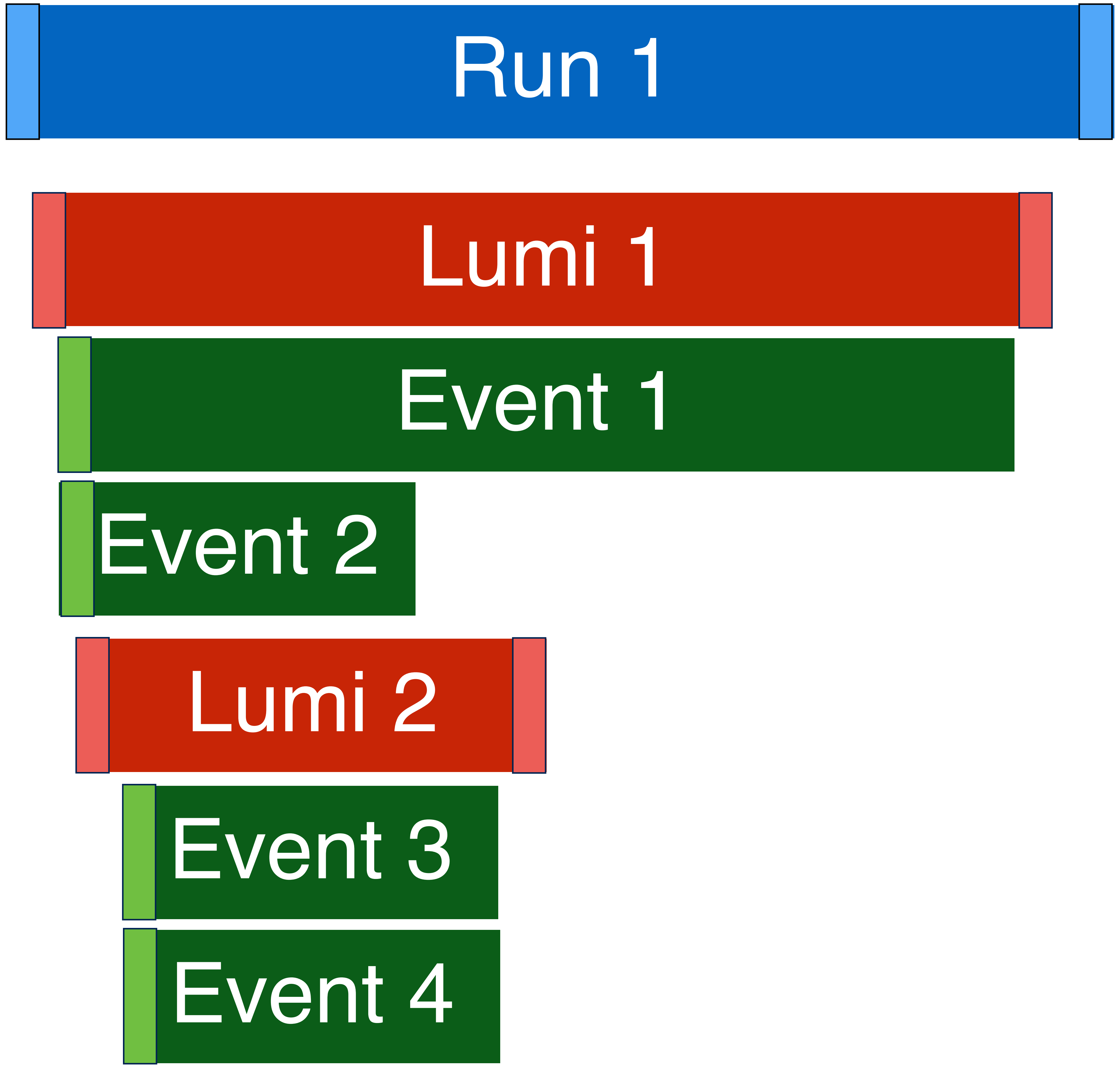


Original Concurrent Transitions



Fully Concurrent Transitions



Constraining Memory

- CMS' driving force for multi-threading is to reduce memory usage
  - Allows average memory per core to be decreased

- Configuration used to set limits
  - Independently control number of allowed concurrent events, lumis and runs

Shared Resources and Task Queues

- All work in the framework is done via TBB tasks

- Tasks needing the same resource are placed in a queue
  - Each unique resource gets its own queue
    - E.g. writing to a particular TFile
    - E.g. processing Lumis

- When a resource is available, the task queue starts a waiting task
  - E.g. when a task using a resources finishes, the queue starts the next task

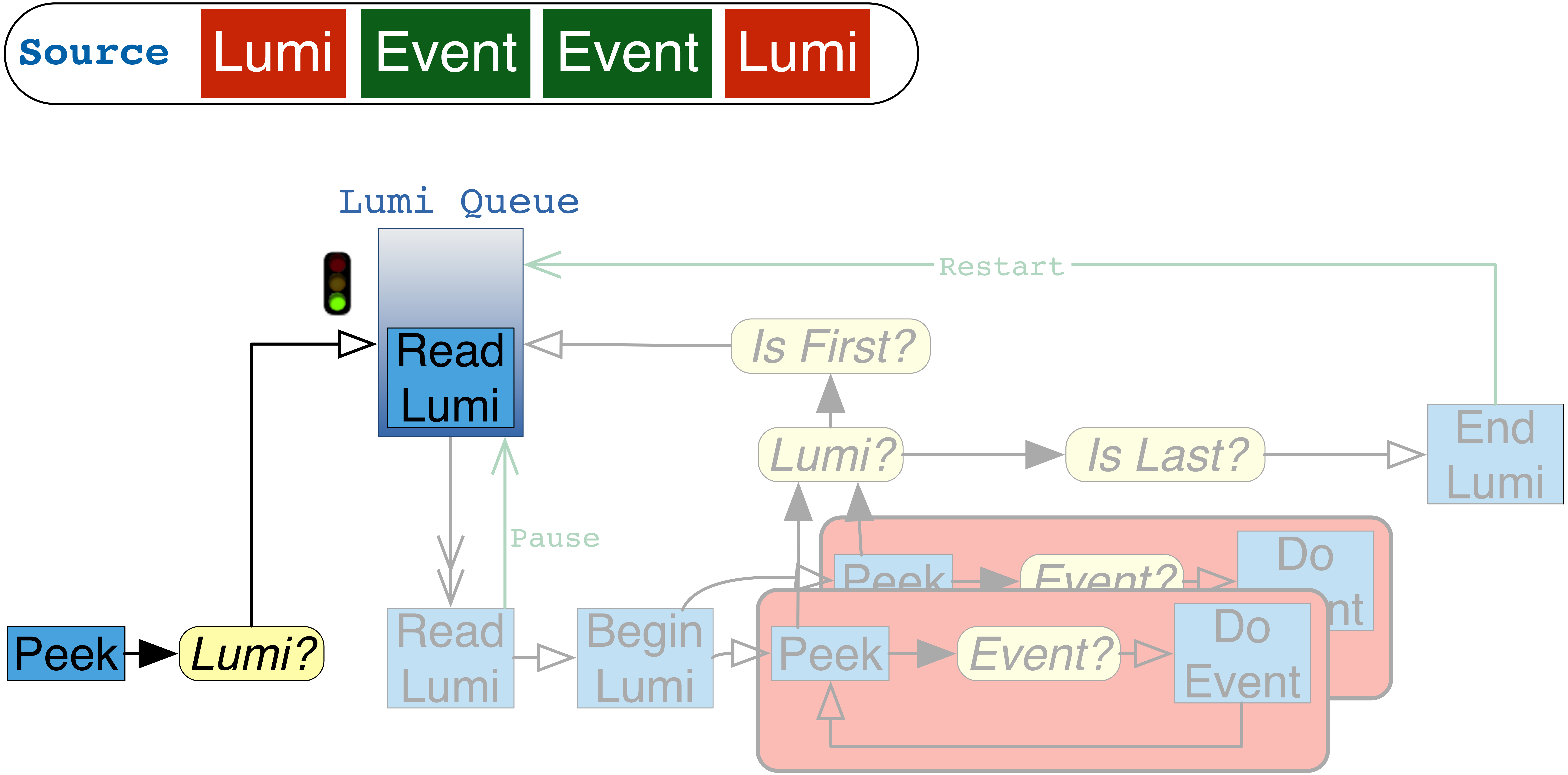
- Chains of tasks needing a resource are handled by pausing the queue
  - When the last task in a chain finishes, the queue is resumed

Lumi Limited Task Queue

- Limited Task Queue
  - Has multiple independent ***lanes*** where each lane runs its own task
  - All lanes pull tasks from the same waiting task list
  - Each lane can be paused/restarted independently
  - If all lanes are paused, no new tasks will be started from the queue

- Number of concurrent Lumis controlled via a queue
  - How many concurrent Lumis is set in the configuration to constrain memory use

Lumi Processing with Queue



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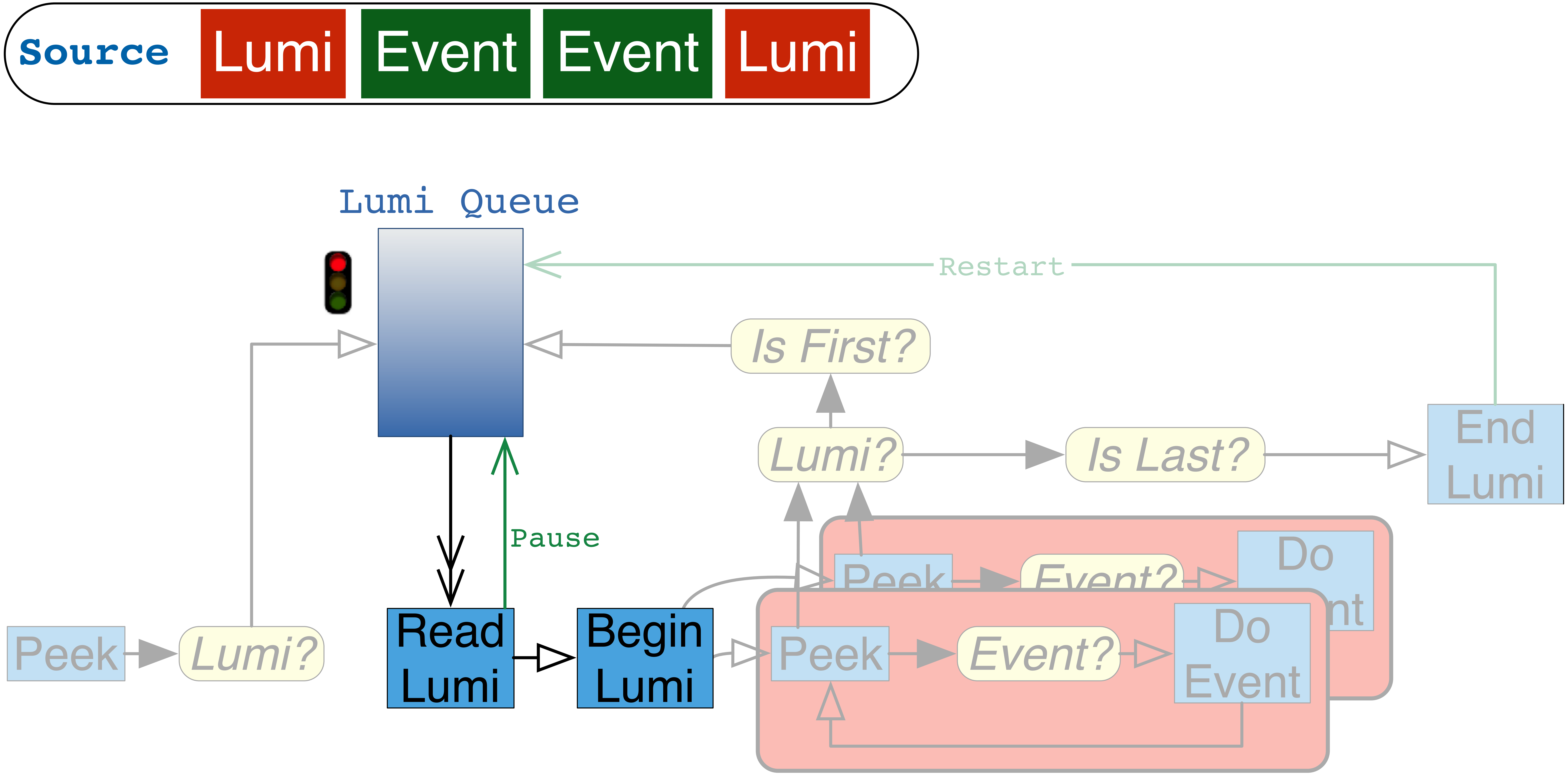

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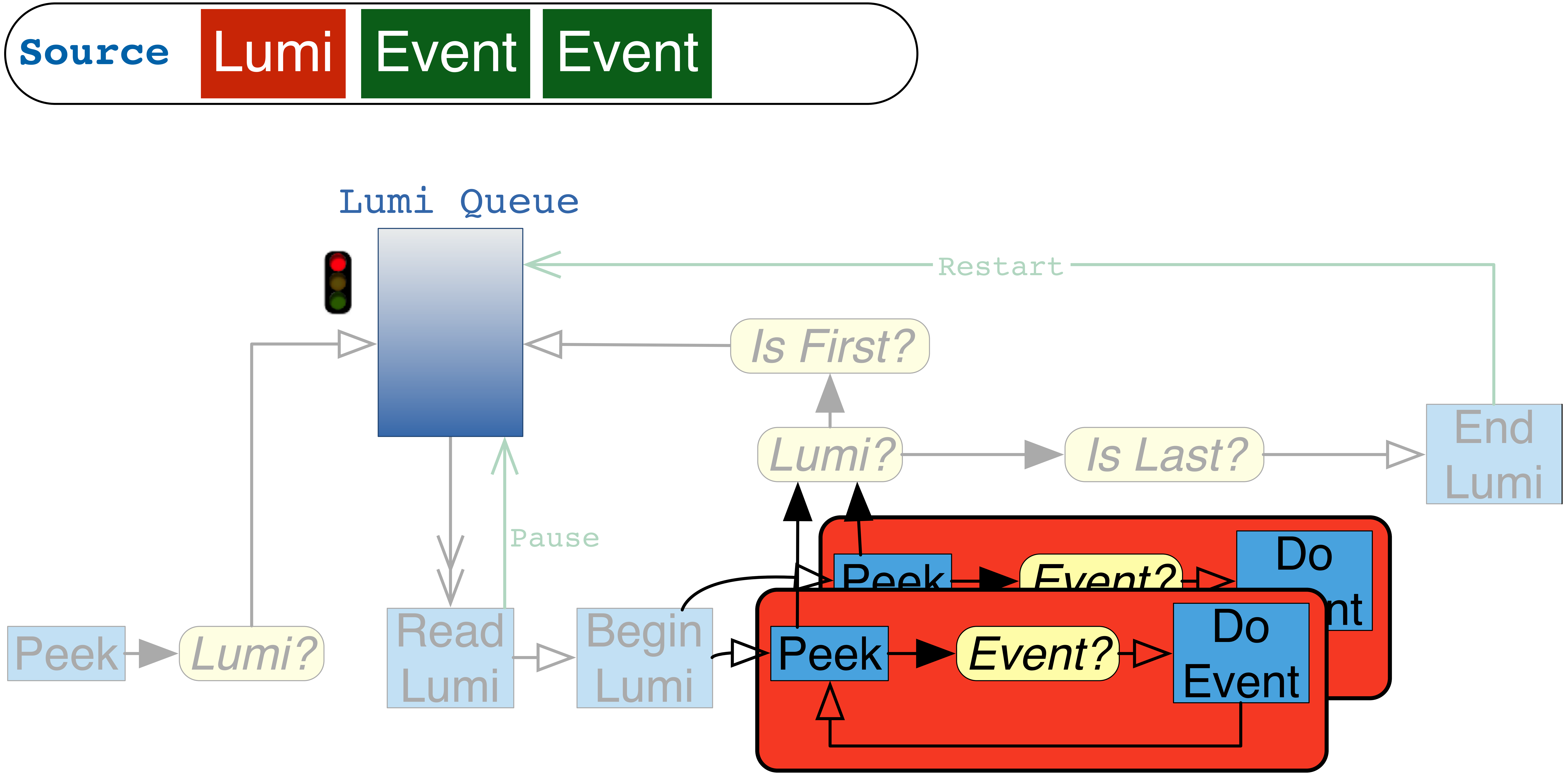
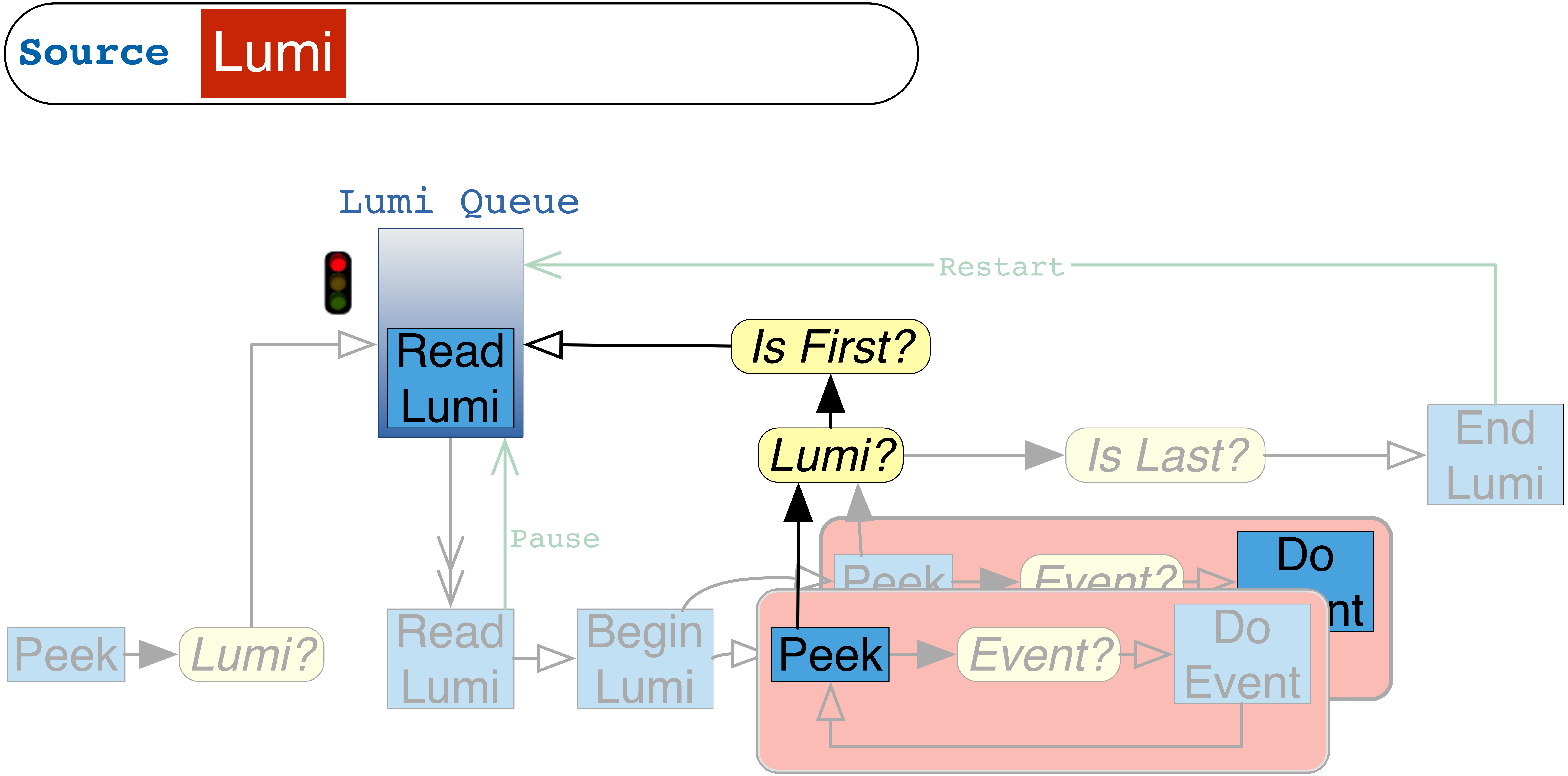


Source
Lumi
Event
Event

Lumi Queue
Restart
Is First?
Lumi?
Is Last?
End Lumi
Pause
Peek
Lumi?
Read Lumi
Begin Lumi
Peek
Event?
Do
nt
Peek
Event?
Do Event

Lumi Processing with Queue



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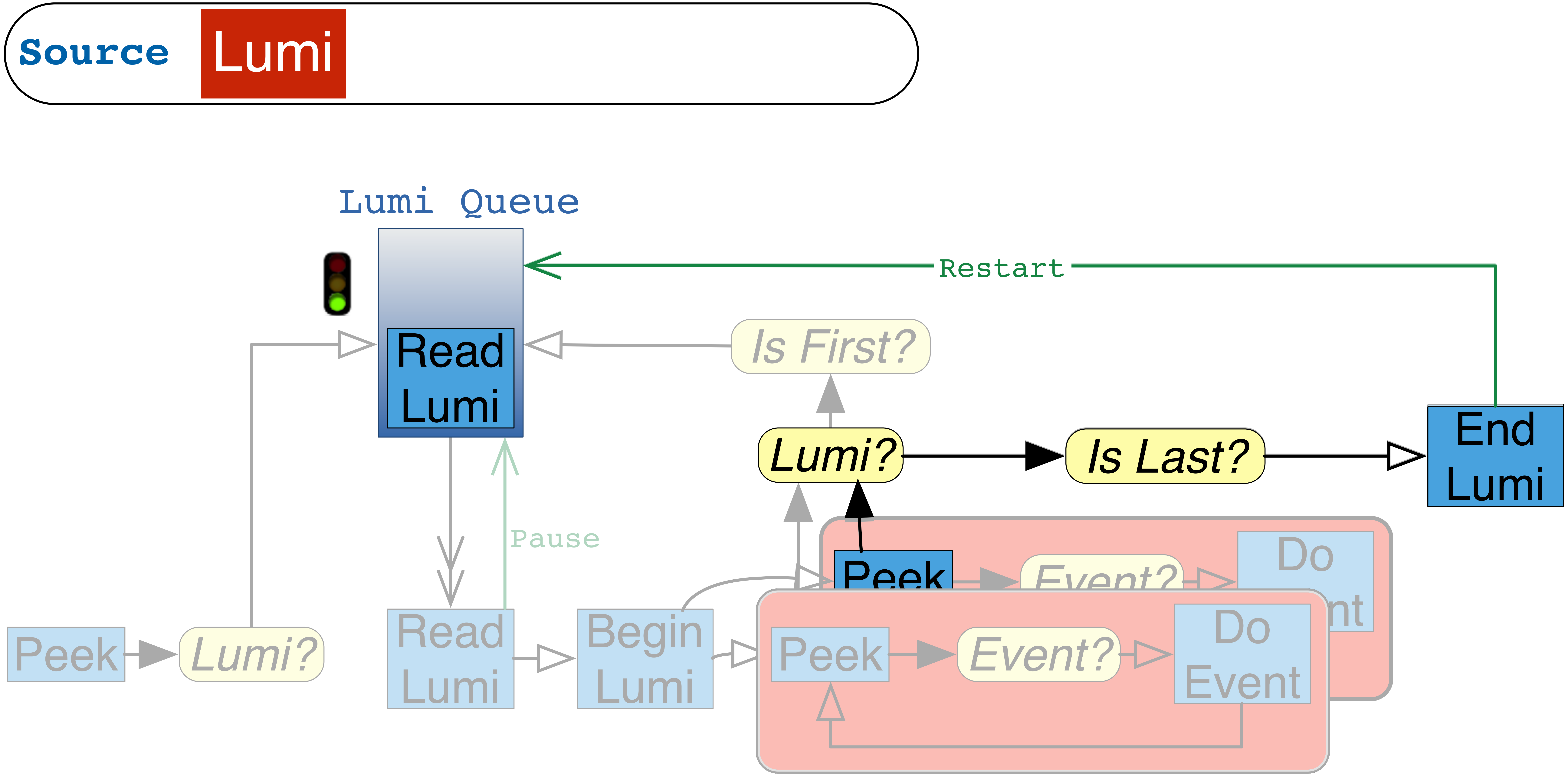


Measurements

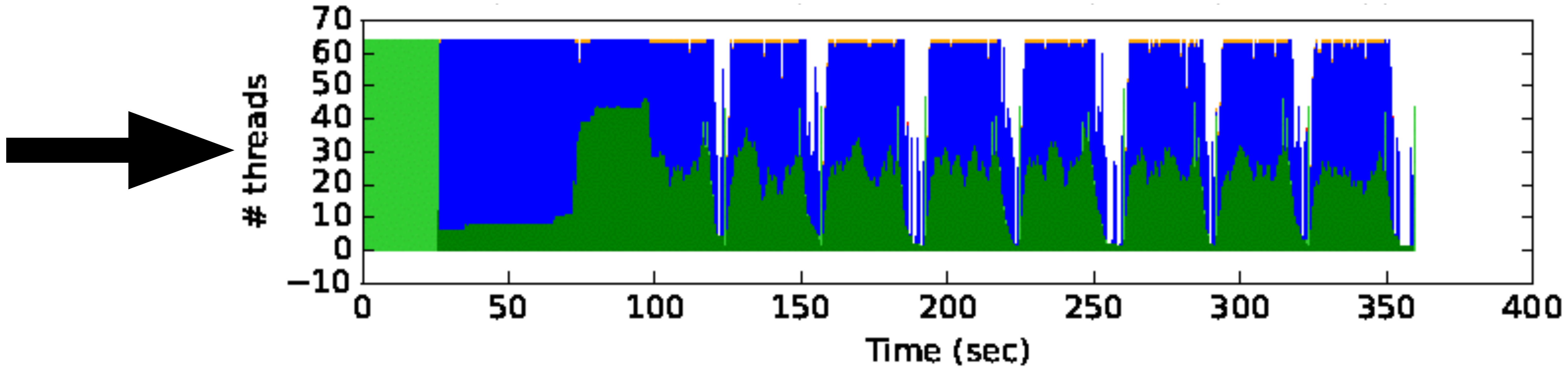
- Input file
  - 1 Run
  - 8 Lumis
  - 200 events per Lumi
- Standard CMS reconstruction job
- KNL Hardware
  - Use 64 threads
- Measurement variations
  - Only one Lumi at a time
  - 8 concurrent Lumis

Reading Concurrency Plots

Total number of concurrent modules

Perfect efficiency when

number of modules == number of threads



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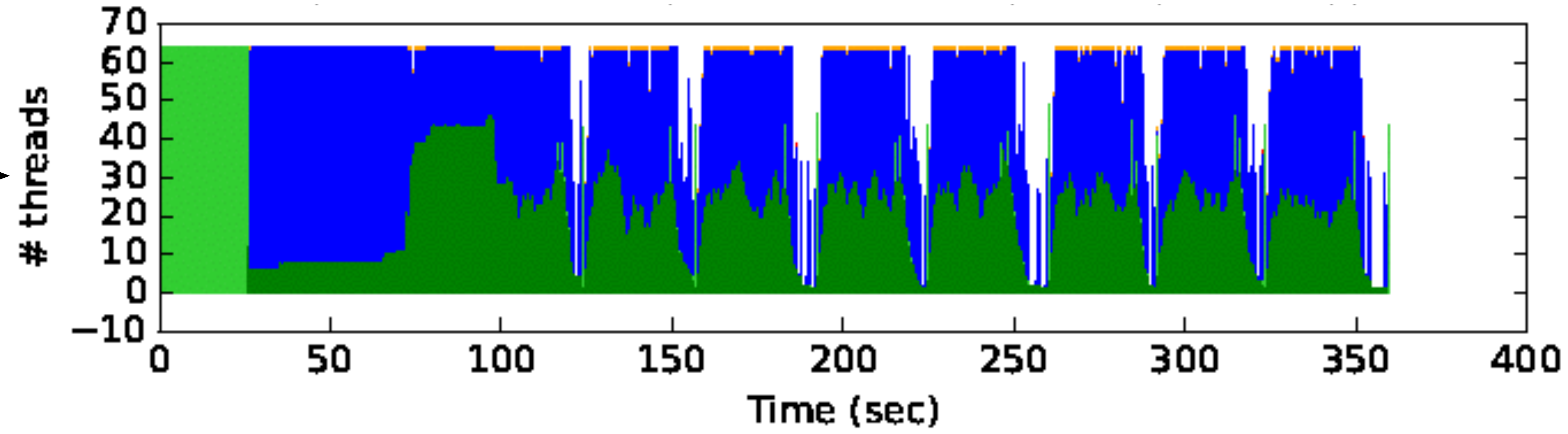
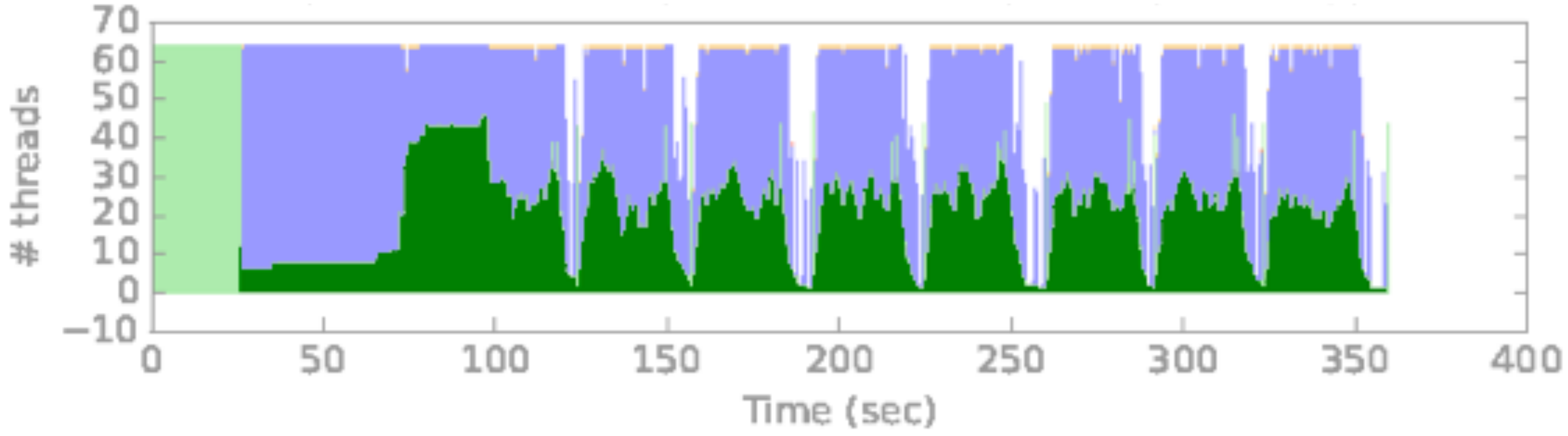


Dark Green

Number of concurrent events with modules actually running



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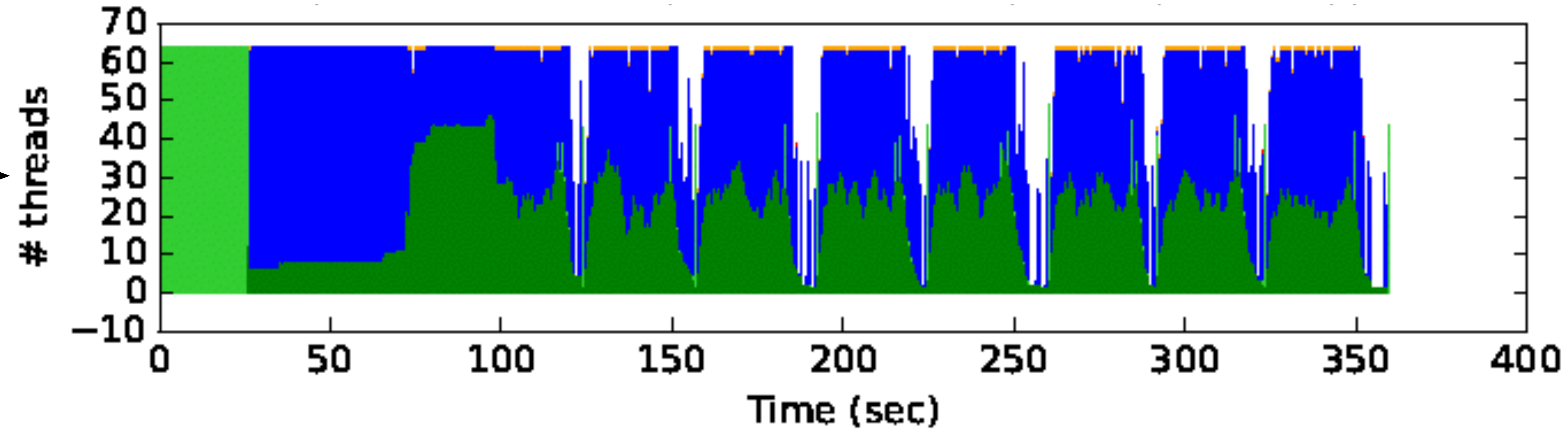

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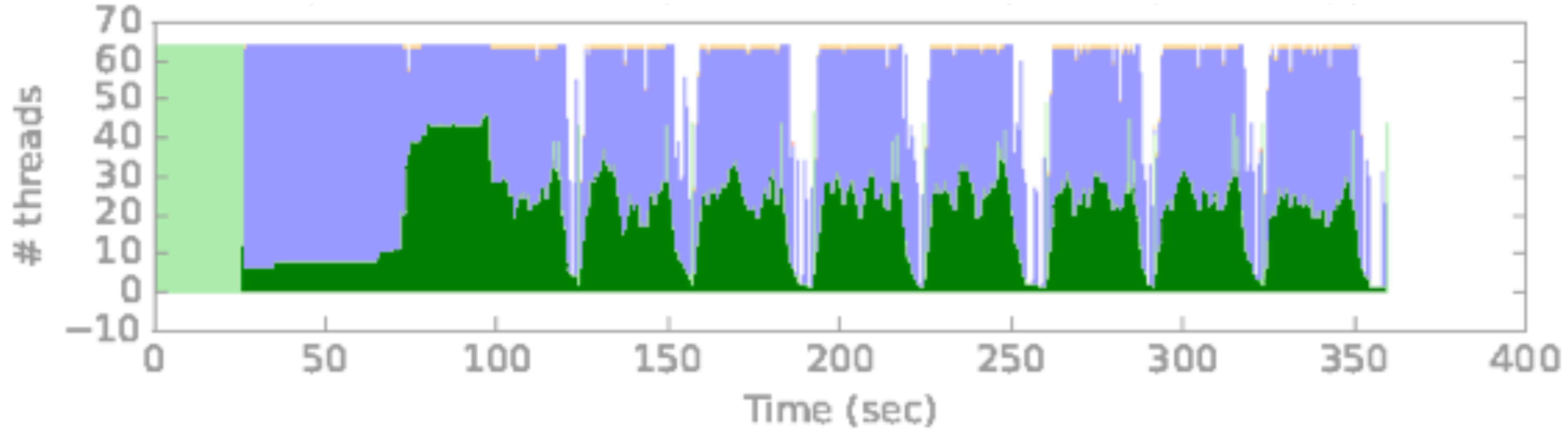
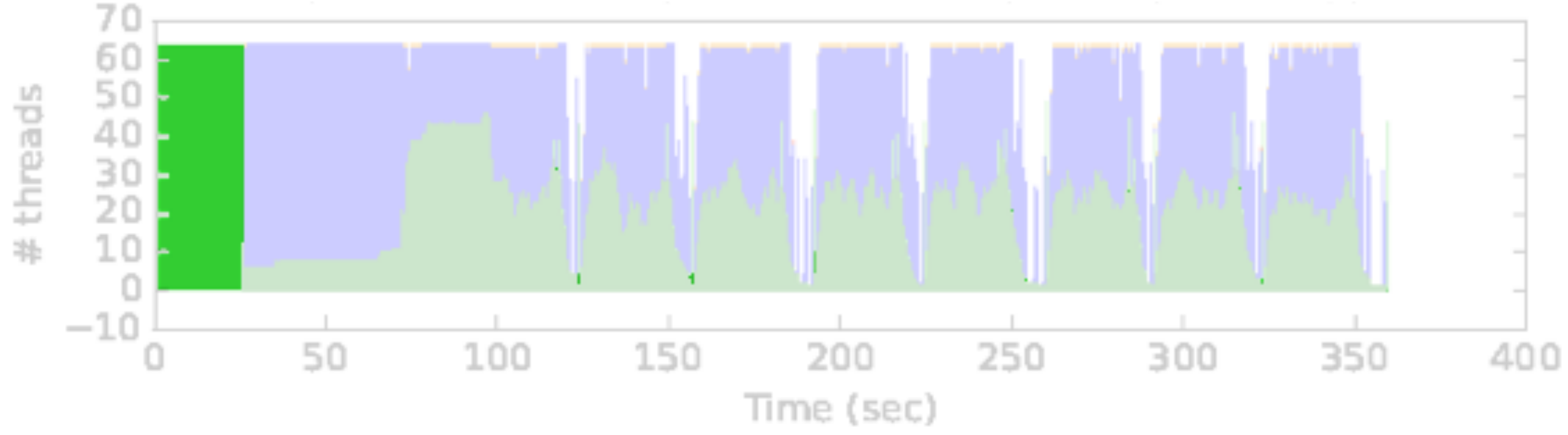


Light Green

Number of concurrent modules processing Lumis or Runs

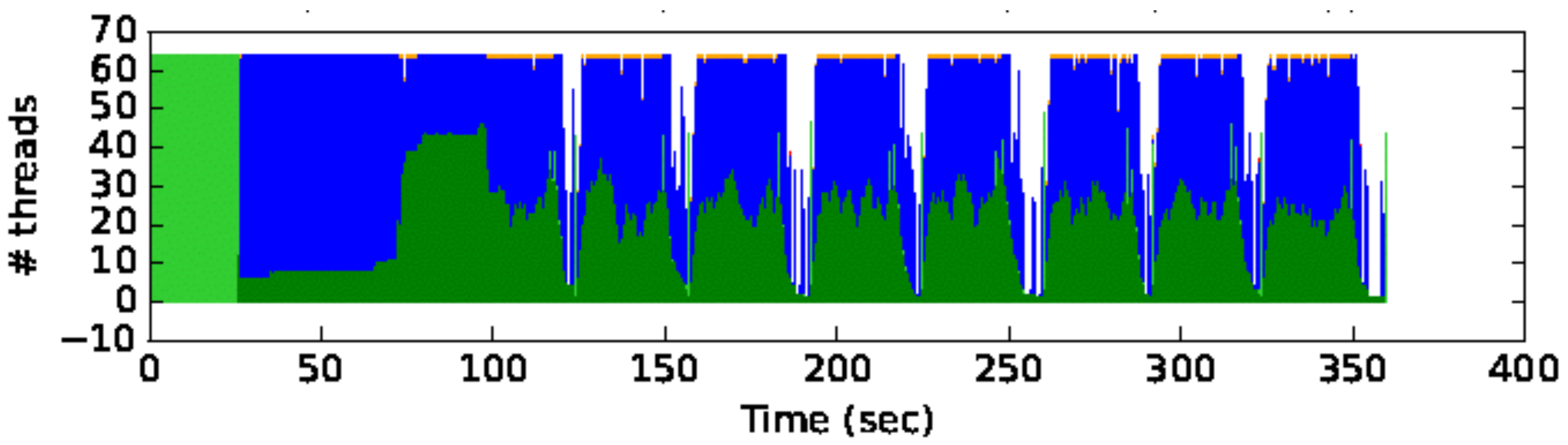


Measurement Results

Single Lumi

Synchronizing on Lumi Boundaries

Thread utilization is poor



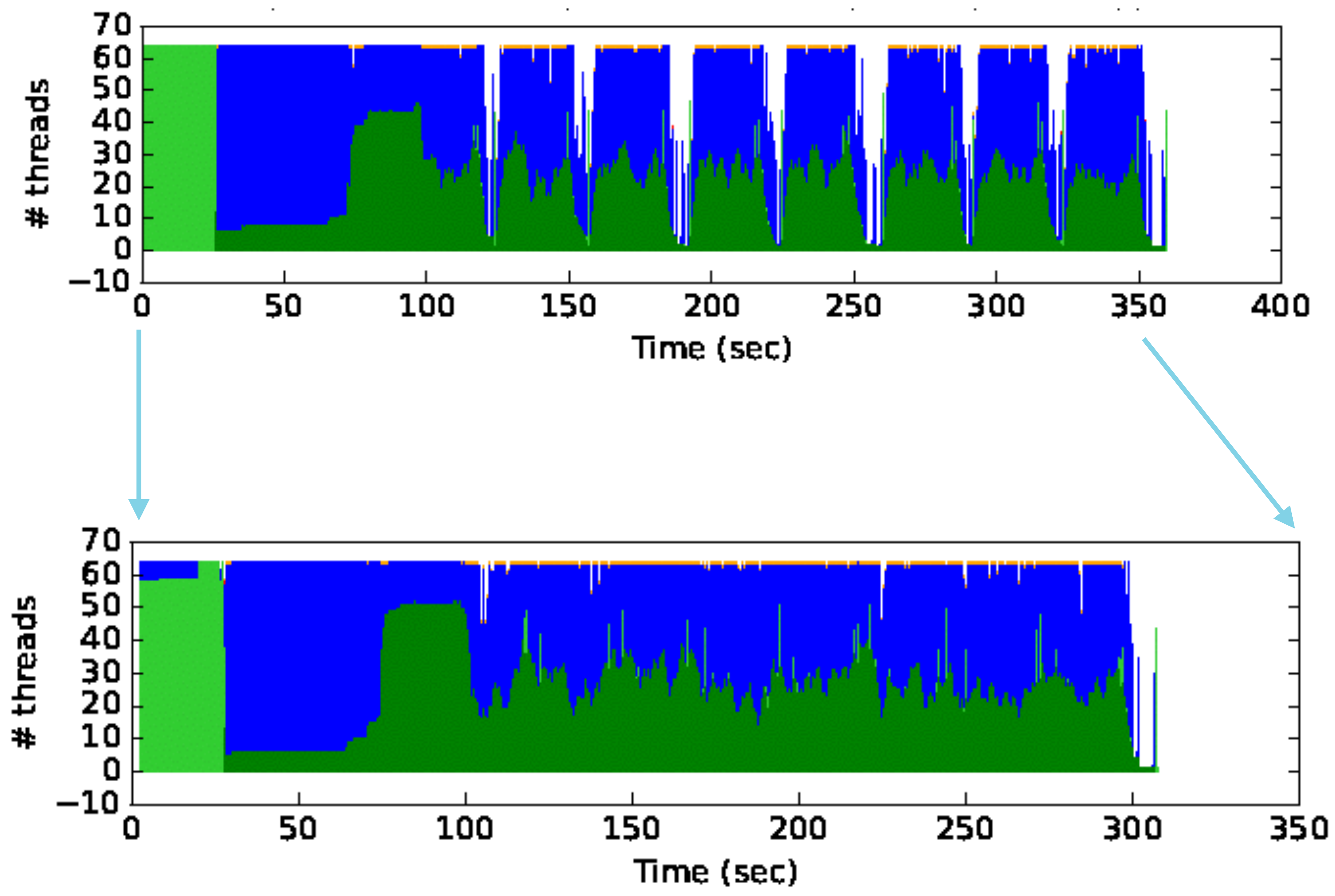
Results

Single Lumi

- Synchronizing on Lumi Boundaries
- Thread utilization is poor

8 Concurrent Lumis

- Synchronizations are gone
- Excellent thread utilization
- Job finishes faster (~15%)

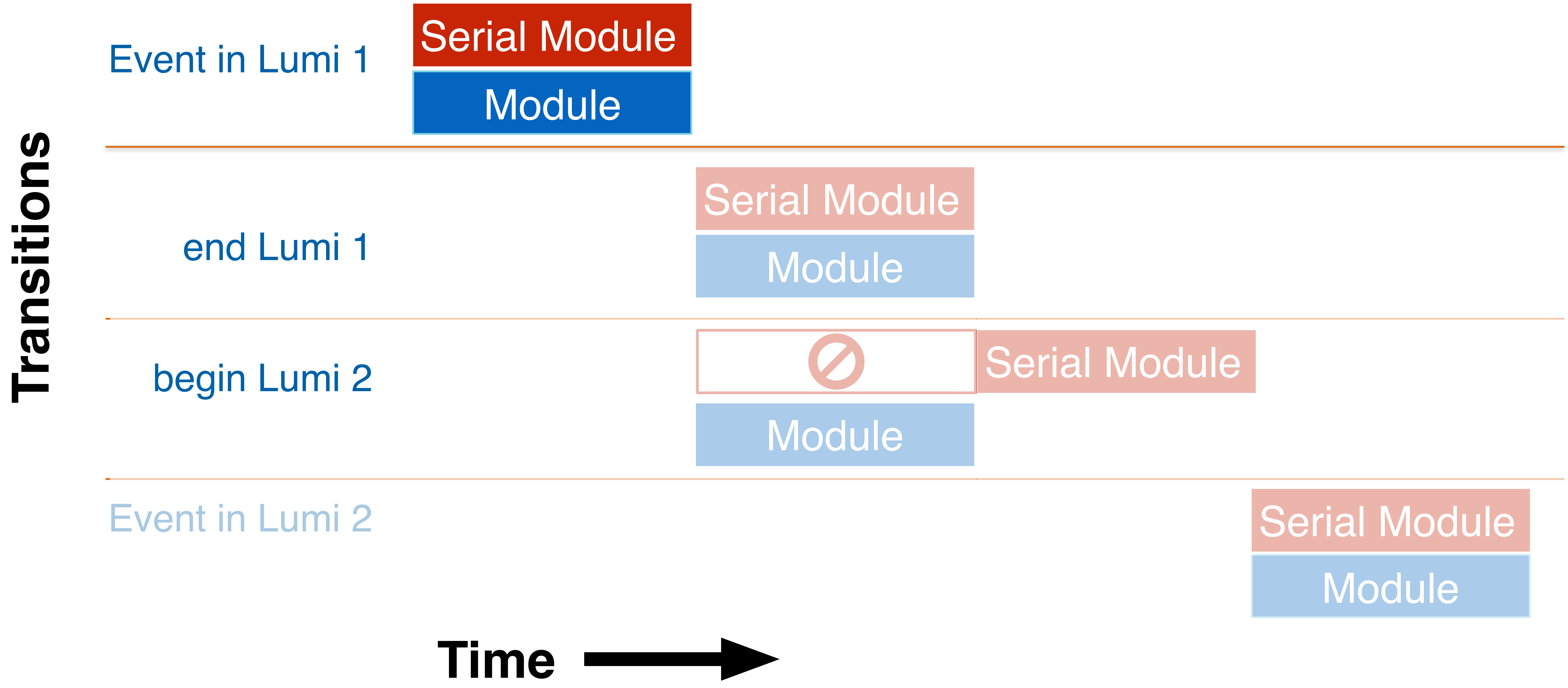


Complication

- CMS supports modules which can only handle one thread at a time
  - The framework serializes access to those modules

- Serial module can *opt in* to see Lumi and/or Run transitions
  - Module will not see next Lumis beginLumi until it has seen last Lumis endLumi

Serial Modules and Lumis



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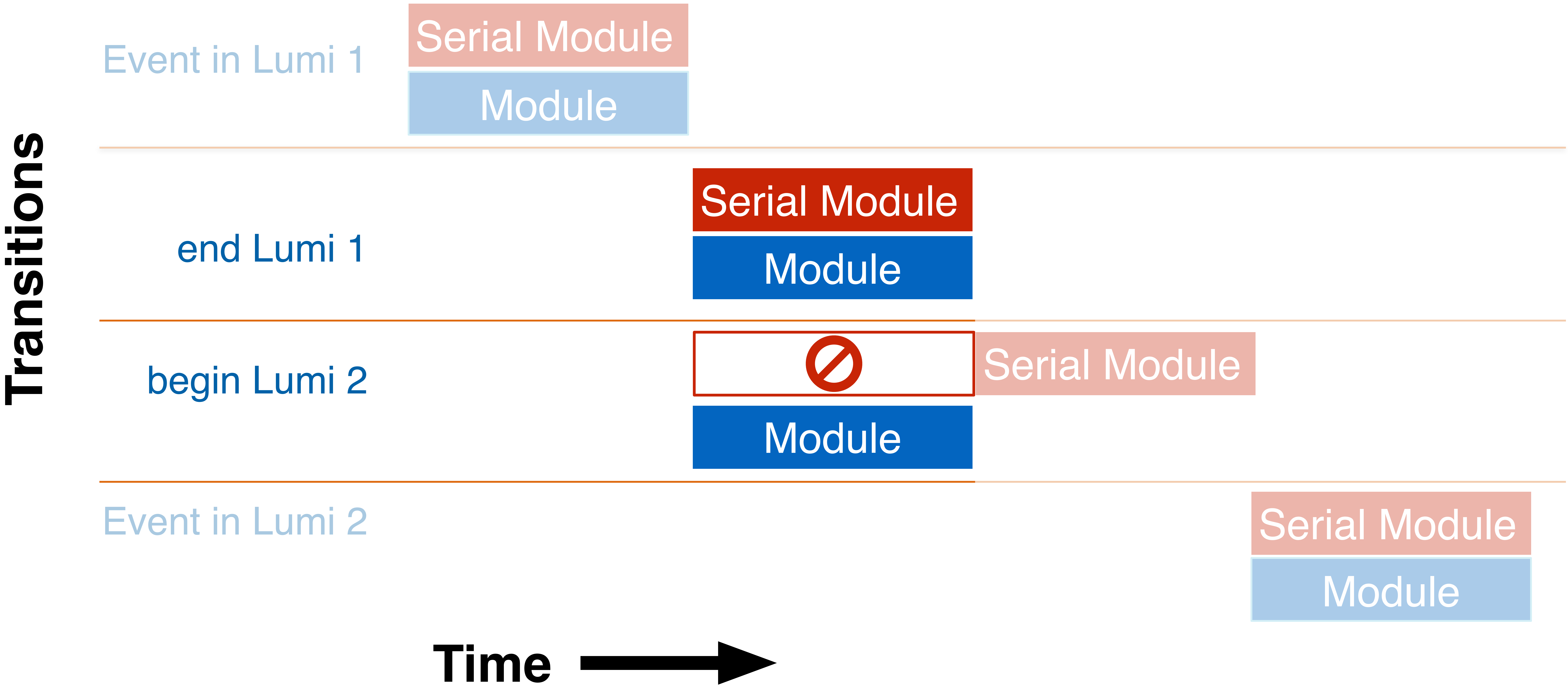

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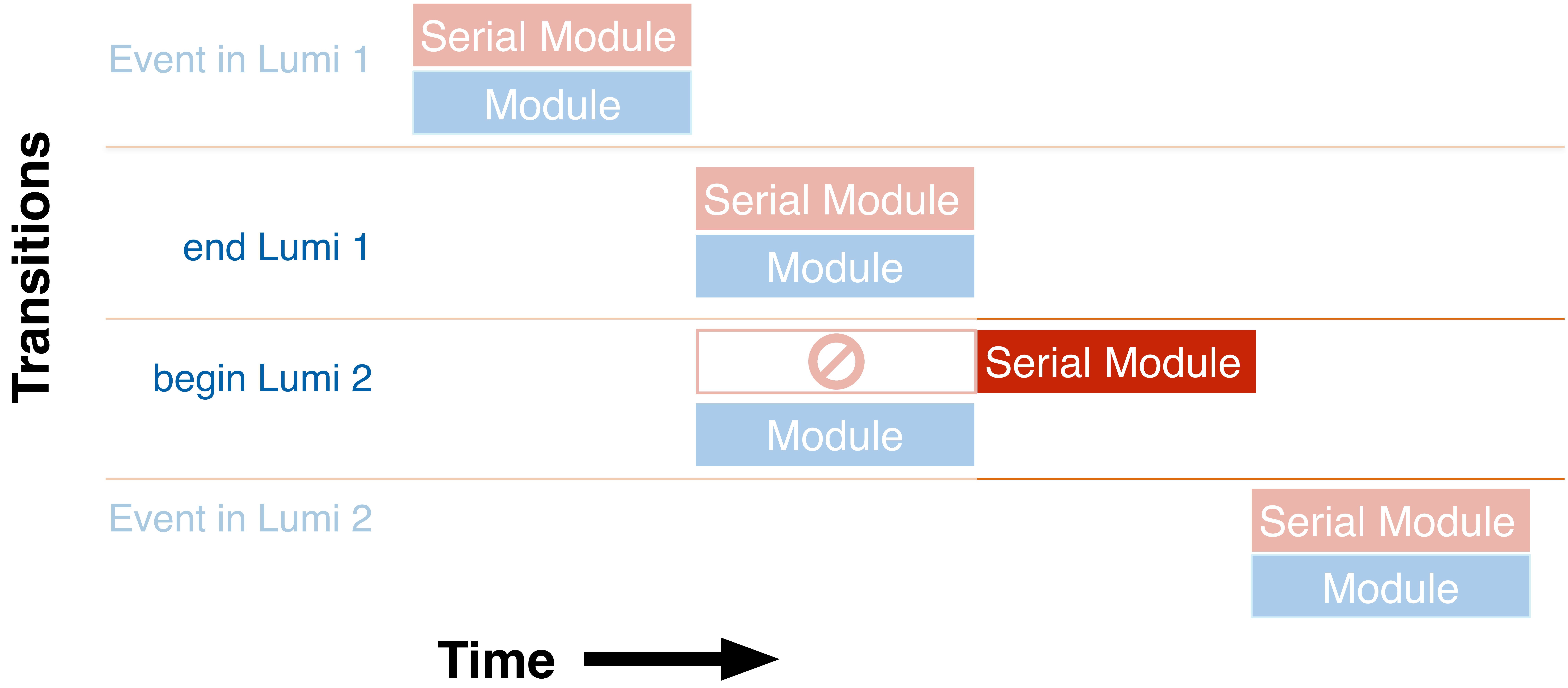

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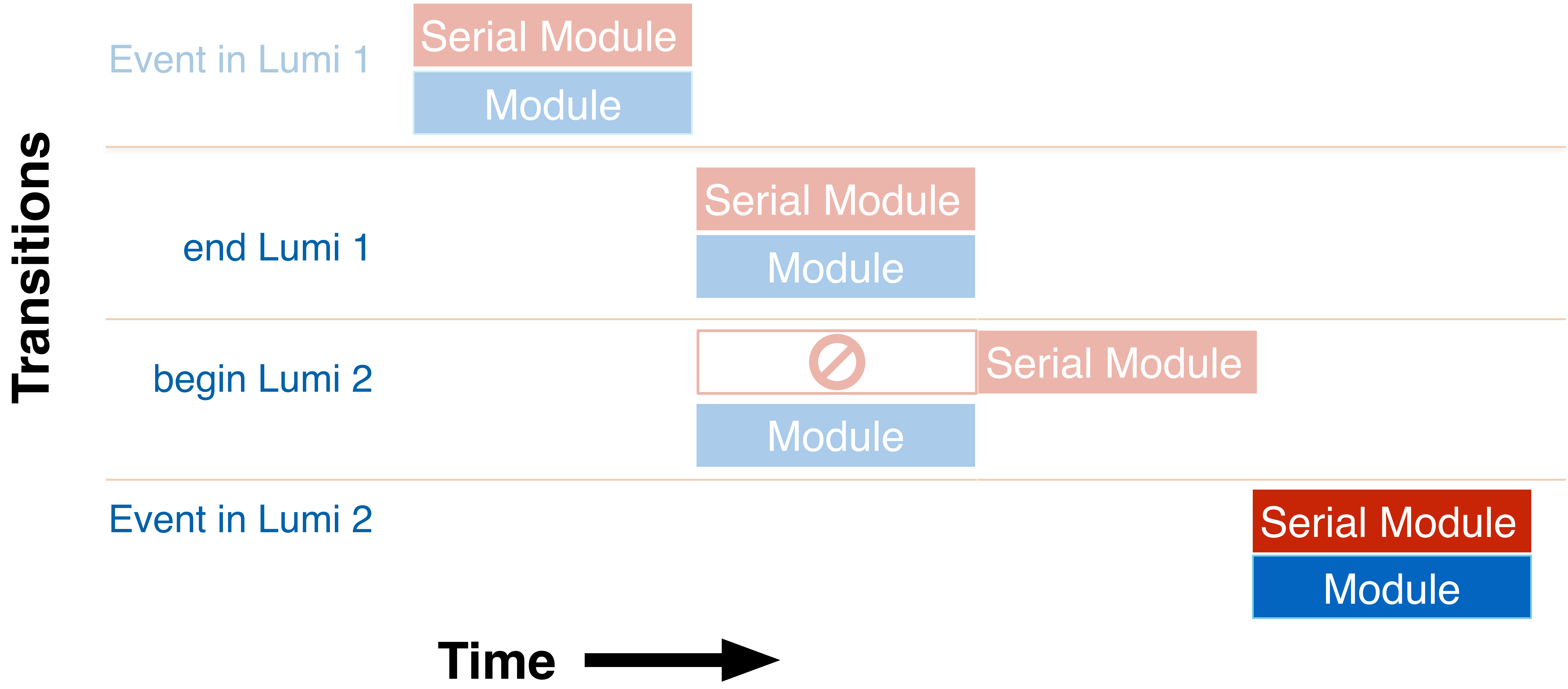


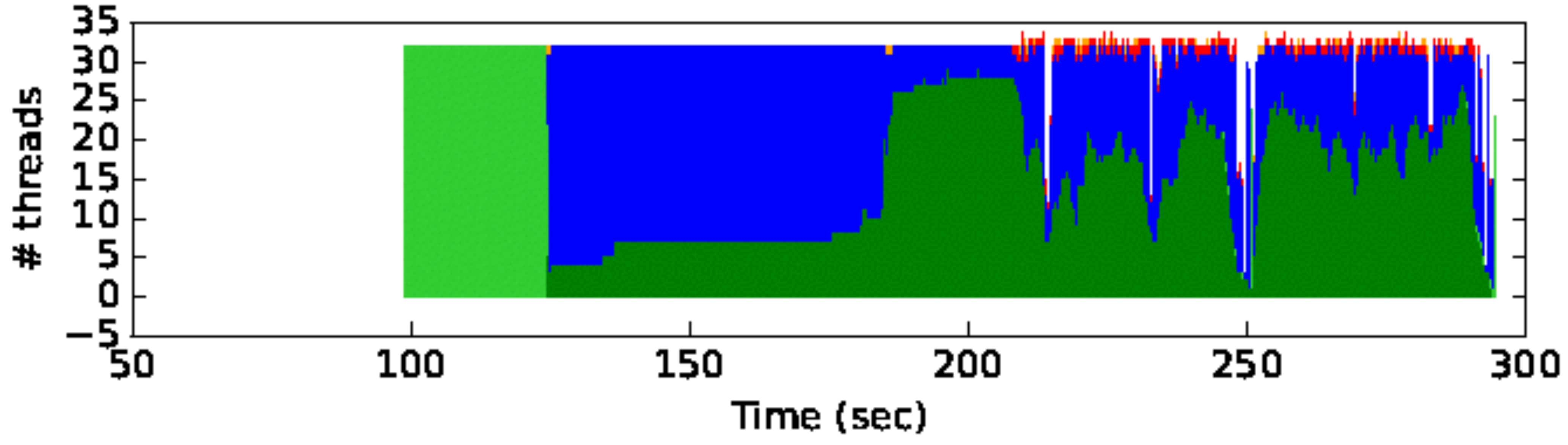
Serial Module and Concurrent Lumis

Just 1 Serial Module in the job

opted in for Lumi transitions

Synchronizing on Lumi boundaries again

Events from new Lumi wait until module completes old Lumi



Conclusion

CMS can concurrently process events across Lumi boundaries

- Increases Event throughput
- Allows more efficient processing of files with few Events per Lumi

Task queues are helpful to manage shared resources

Full utilization is hampered by serial modules which watch Lumis