Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

Accelerator Integration in CMS

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Considerations for Heterogeneous Computing

Scheduling CPU & Accelerator Algorithms

Configuring Heterogeneous Jobs

Scheduling CPU & Accelerator Algorithms

Concurrent CPU/Non-CPU Processing

CMS data processing framework uses a mechanism to interact effectively with non-cpu resources

Non-CPU algorithms are divided into 3 phases

- CPU stage which acquires data and transfers to non-CPU resource
- Non-CPU algorithm is then run
- When finished, a publish step is run on the CPU to move data back to CPU memory

While non-CPU algorithm runs, the CPU is available for other algorithms

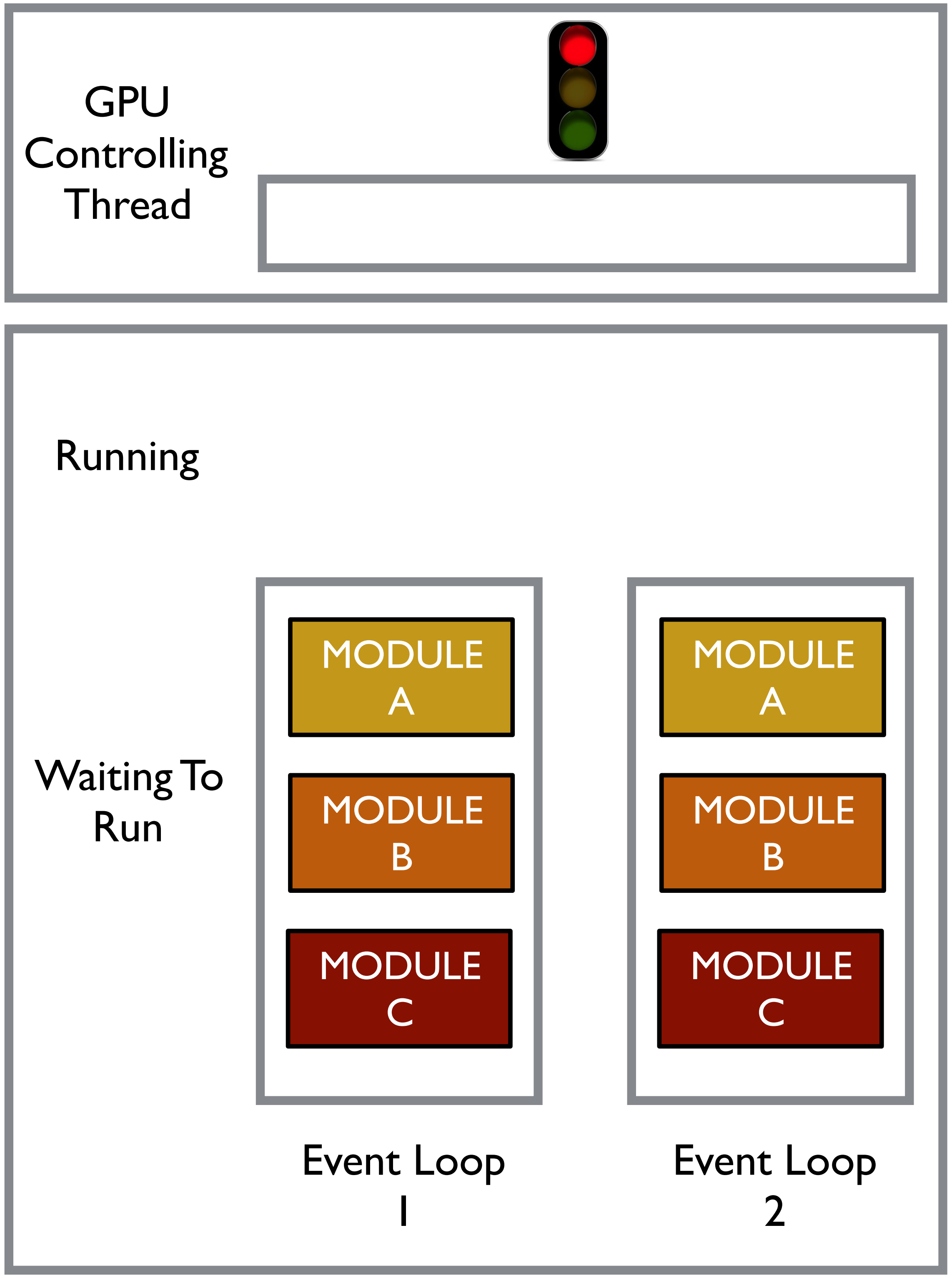
Setup

TBB controls running modules

- Can have concurrent processing of multiple events

Have separate helper thread to control GPU

- Waits until enough work has been buffered before running GPU kernel



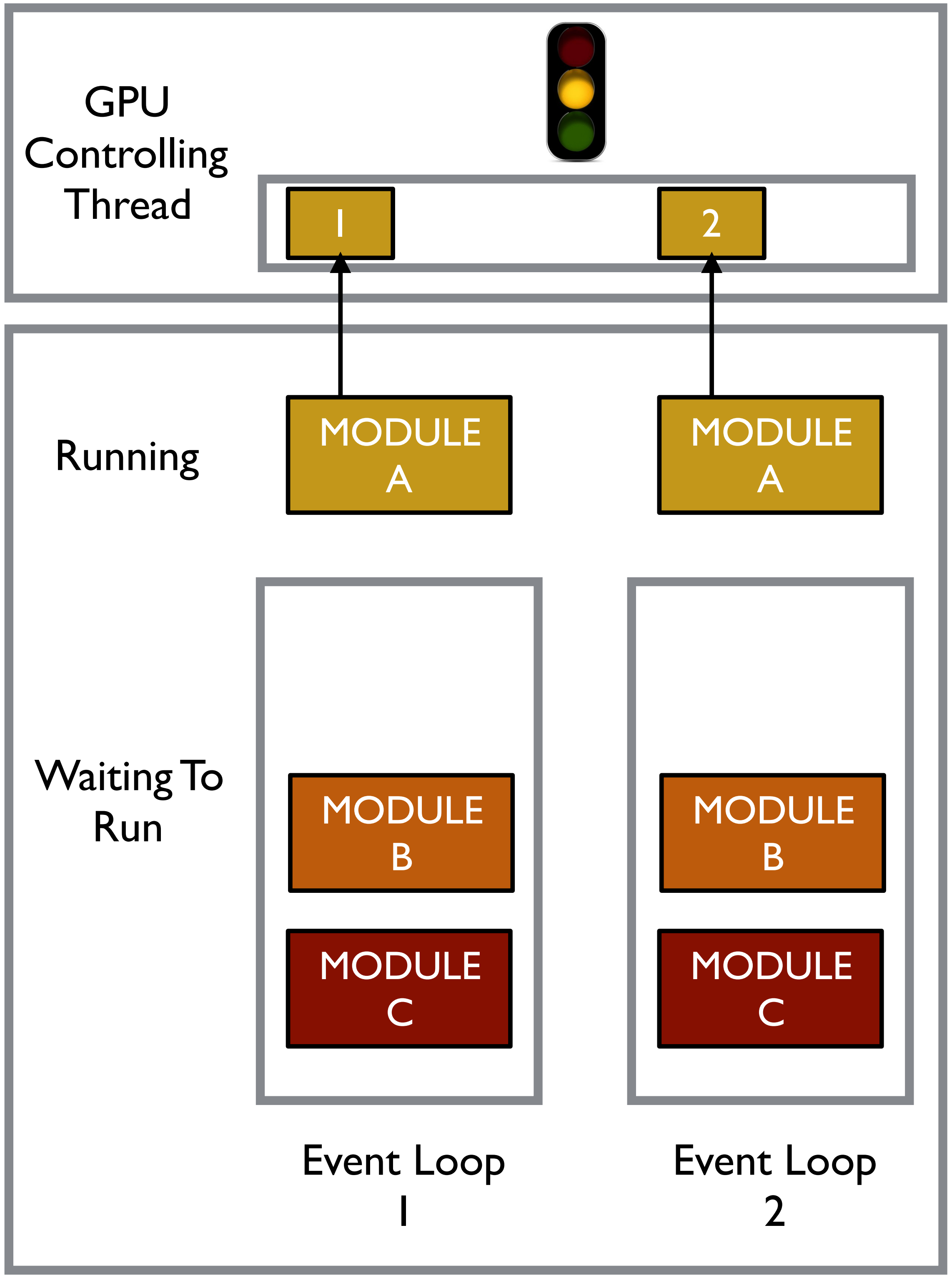
Acquire

Module acquires method called

- Used to pull data from Event

Copies data to buffer

- Includes a callback to start next phase of module running

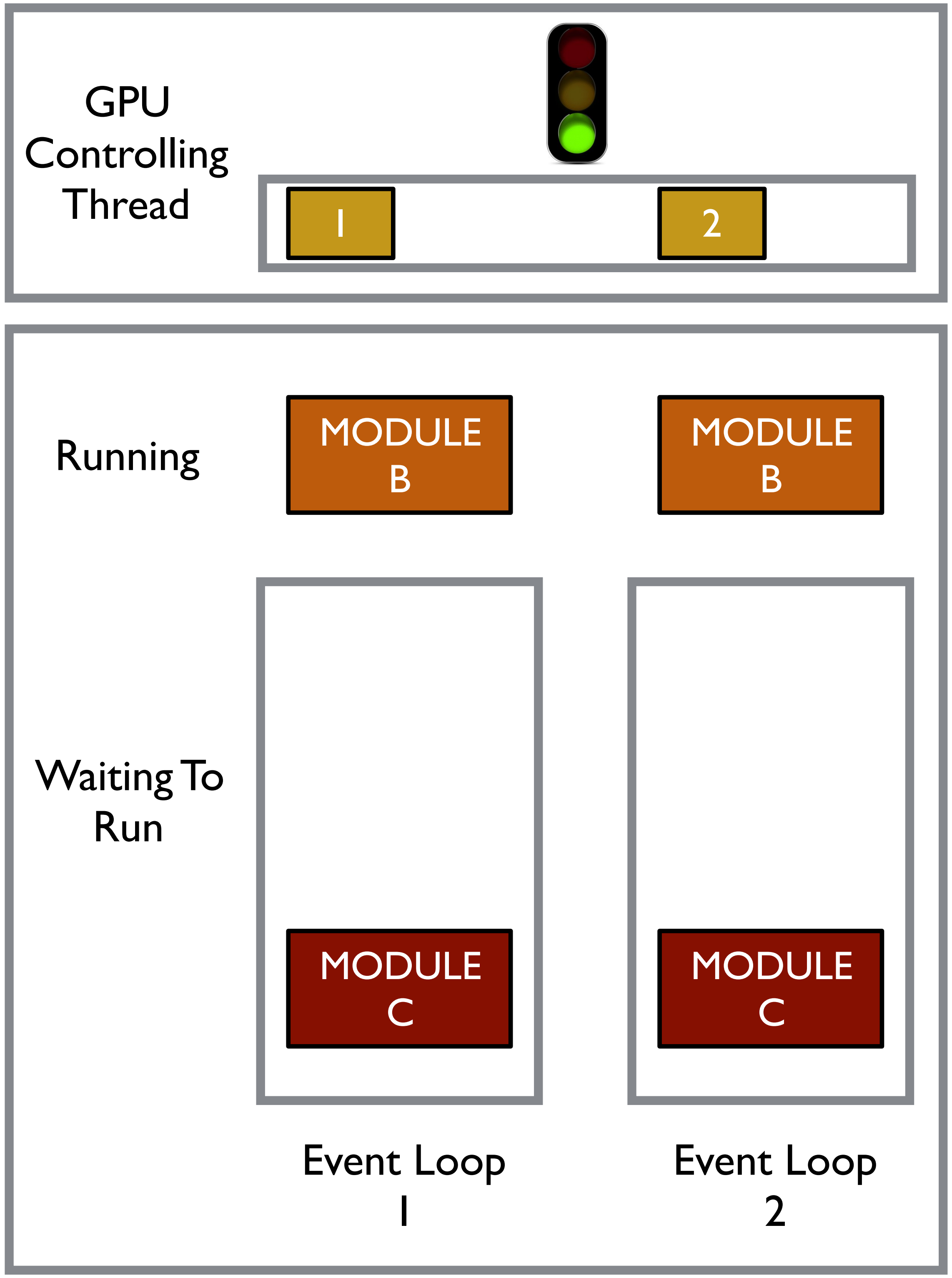


External Work Starts

GPU kernel is run

- Data pulled from buffer

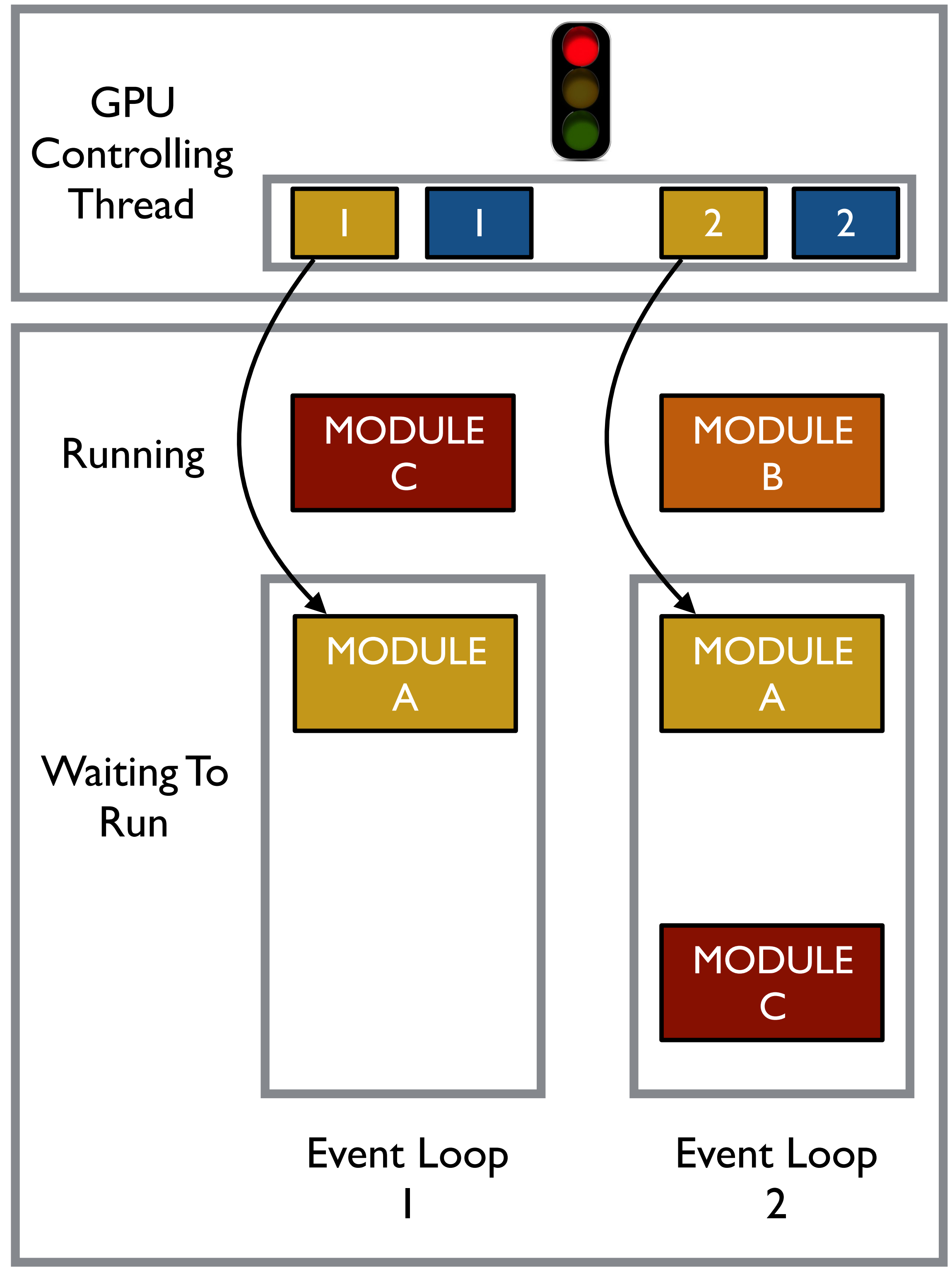
Next waiting module can run



External Work Finishes

GPU results are copied to buffer

Callback puts Module back into waiting queue

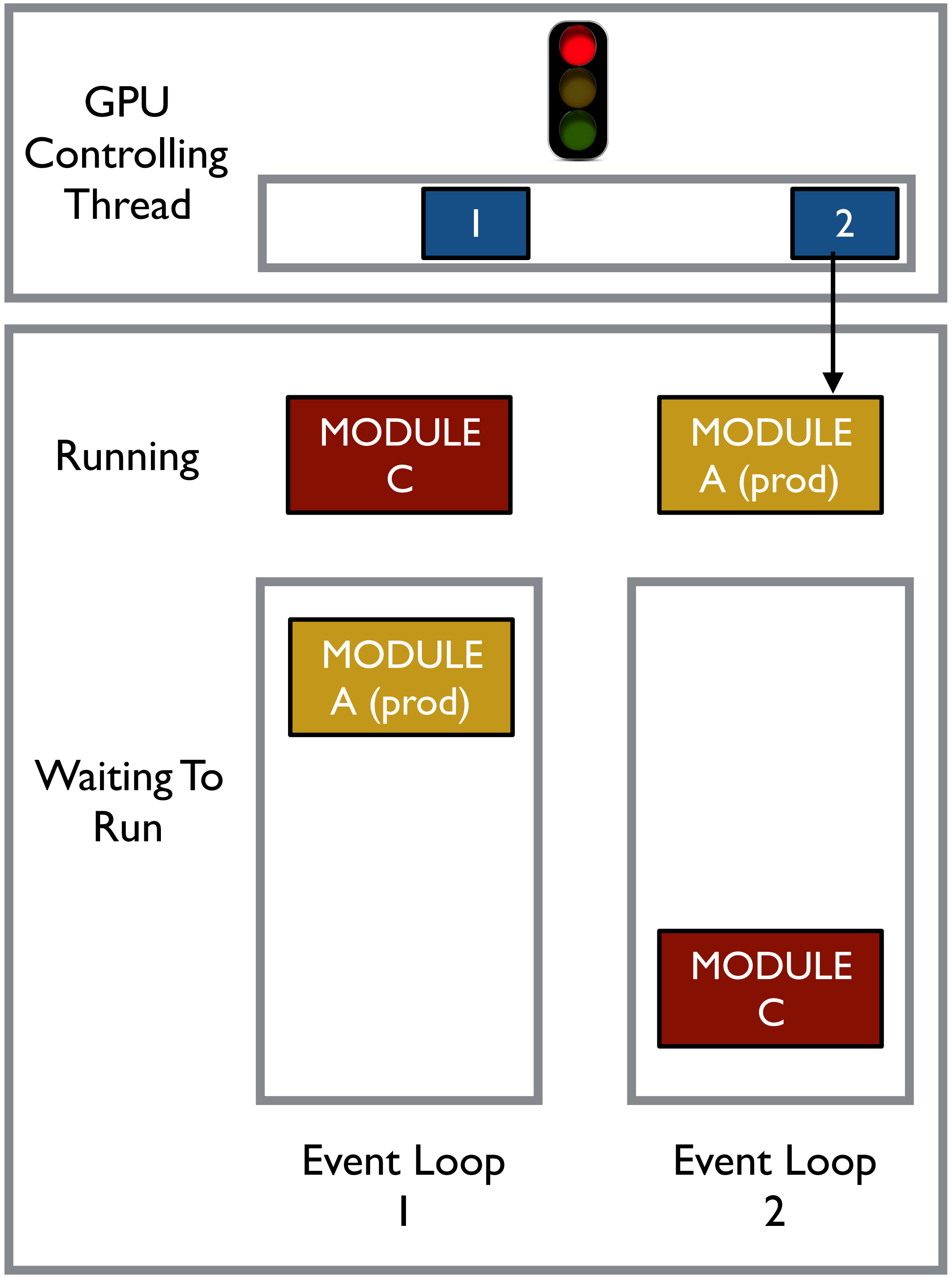


Produce

Produce method of module is called

Pull data from buffer

Data used to create objects to put into Event



External Work in Practice

GPU

- HLT base R&D have been using the facility
- See Matti Kortelainen’s talk in this session

Remote FPGA

- R&D project which uses remote (on or off site) FPGA for machine learning inference
- See Kevin Pedro’s talk Wednesday in ‘Reconstruction and Software Triggers’

Geant V CMS Integration R&D

- Control of thread passed to Geant V when new Event is ready
  - Geant V is using TBB task to run its code
  - This allows proper thread pool sharing with framework also using TBB tasks
- When Geant V finishes an Event, control returns to framework
  - The finish thread often different than the start thread
- See Kevin Pedro’s talk Thursday in ‘Detector Simulation'

External Work and Event Batching

Framework supports running more concurrent events than threads

Normally not a useful configuration

- increases memory use
- does not increase event throughput

External Work modules can process events in batches

module waits to run external algorithm once it has acquired a certain number of events

Has been used in framework tests

Not being used by any R&D projects

- complicates module book-keeping

Some simple tests showed batching can decrease event throughput

Have to carefully balance

- per module speed improvements from batching
- possible lack of available tasks for CPU to run while accumulating a batch

Configuring Heterogeneous Jobs

Heterogeneous Configuration

Want jobs for a workflow to run at any site

Want same configuration for all jobs in a workflow

- Be agnostic to the kind of hardware being used for a given job
- Hash of configuration already used by framework to segregate data from different workflows

Want to be able to keep CPU and Accelerator algorithms separate

- No need to touch working code
- The different hardware may want to group the work differently
  - e.g. CPU might want to spread over 3 modules while GPU wants them combined to 1
- Not precluding having CPU and Accelerator algorithm in same module either

Use provenance tracking to determine what technology was used

- Framework tracks what data each module uses for each Event

SwitchProducer

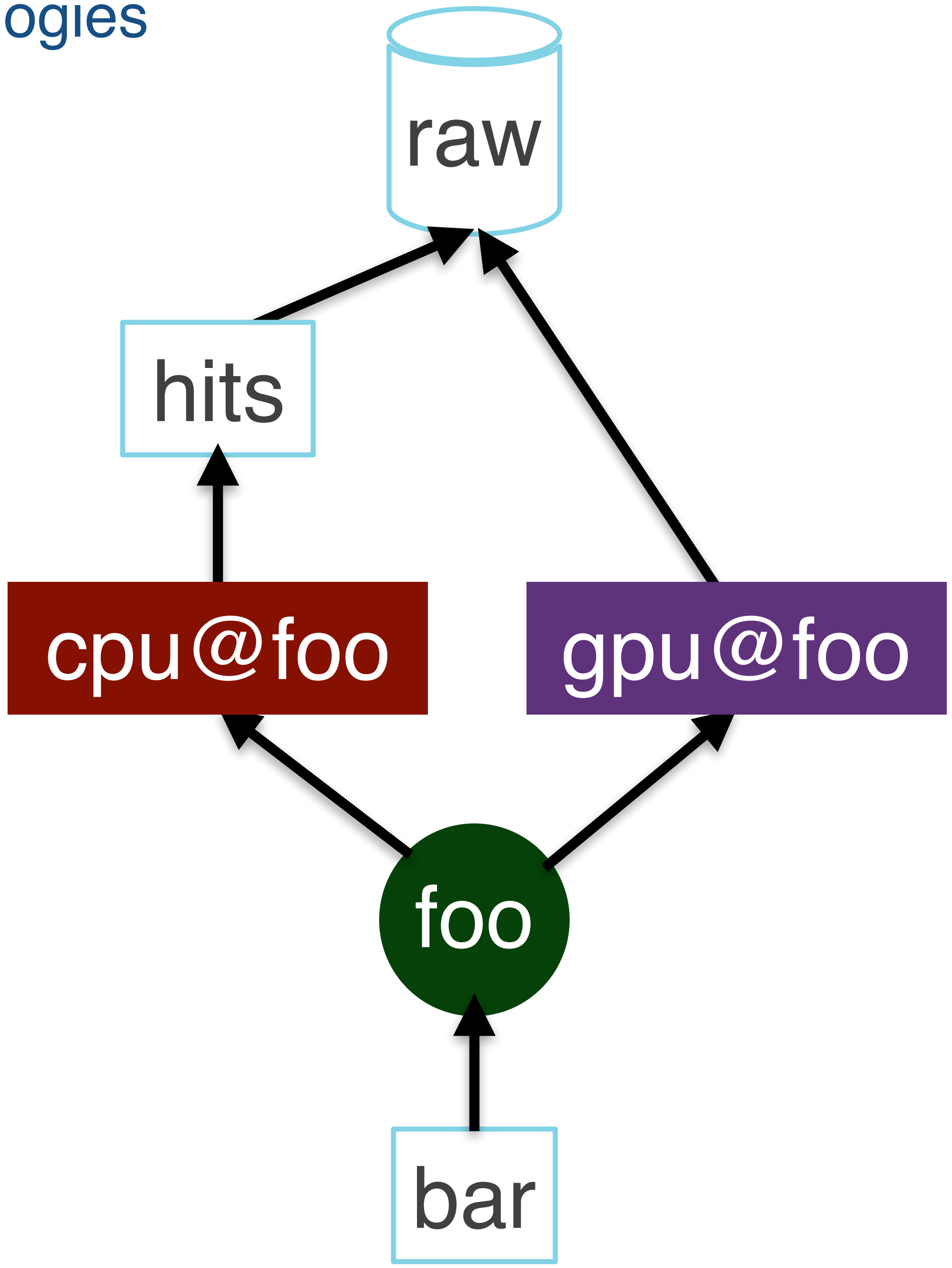
SwitchProducer added to configuration

- Allows specifying multiple modules associated to same module label
- At runtime picks one to use based on available technologies

```
foo = SwitchProducer(
        cpu = Producer("FooProducer",
                       input = "hits"),
        gpu = Producer("FooGPUProducer",
                       input = "raw") )

hits = Producer("HitsProducer",
                input = "raw")

bar = Producer("BarProducer",
               input ="foo")
```



Conclusion

CMS has a mechanism for integrating TBB and accelerators

- Can support any conceivable hardware

Possible future changes only after CMS gains more practical experience

Backup Slides

Throughput Scaling Test

Approximate use of non-CPU resource

- Separate helper thread which sleeps for a set amount of time
- All waiting sleep requests handled concurrently
  - thread sleeps only for the longest requested time, not the total requested time
- Once sleeping, additional sleep requests will have to wait
- Denoted by 'External Work'

Simple CPU based algorithm for testing

- algorithm sleeps for set amount of time

Require that two algorithms are needed to process each event

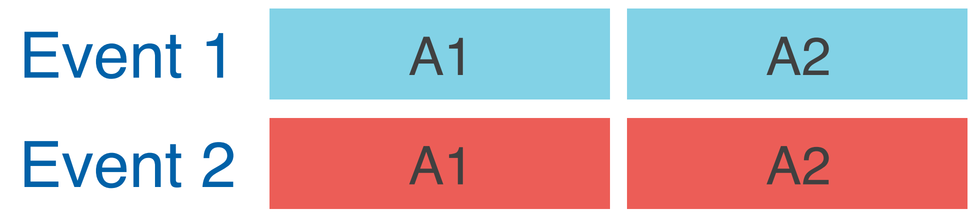
Test two different algorithm dependencies

- The two algorithms are independent of each other
- One algorithm depends on the results of the other algorithm

Expectations for Independent Algorithms

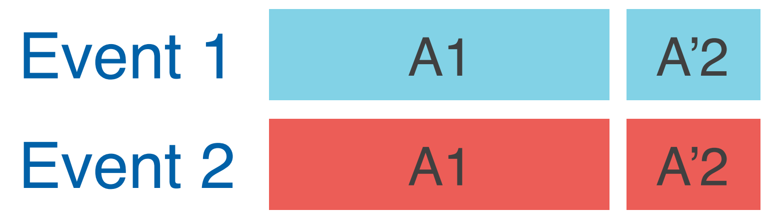
threads = # concurrent events

both CPU algorithms take same time



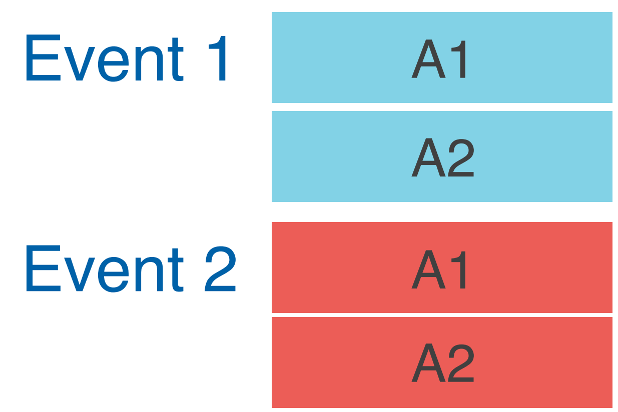
threads = # concurrent events

1 algorithm is faster than other



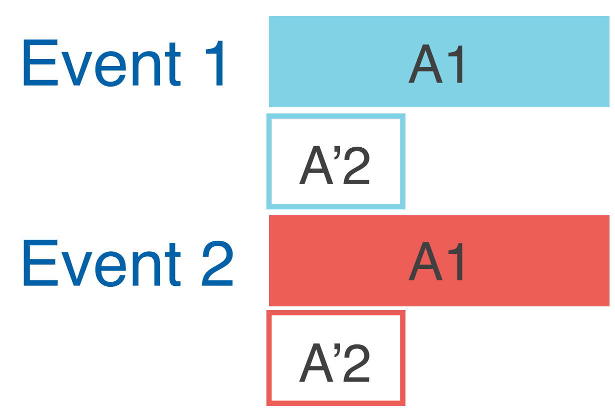
threads = 2 * # concurrent events

both CPU algorithms take same time

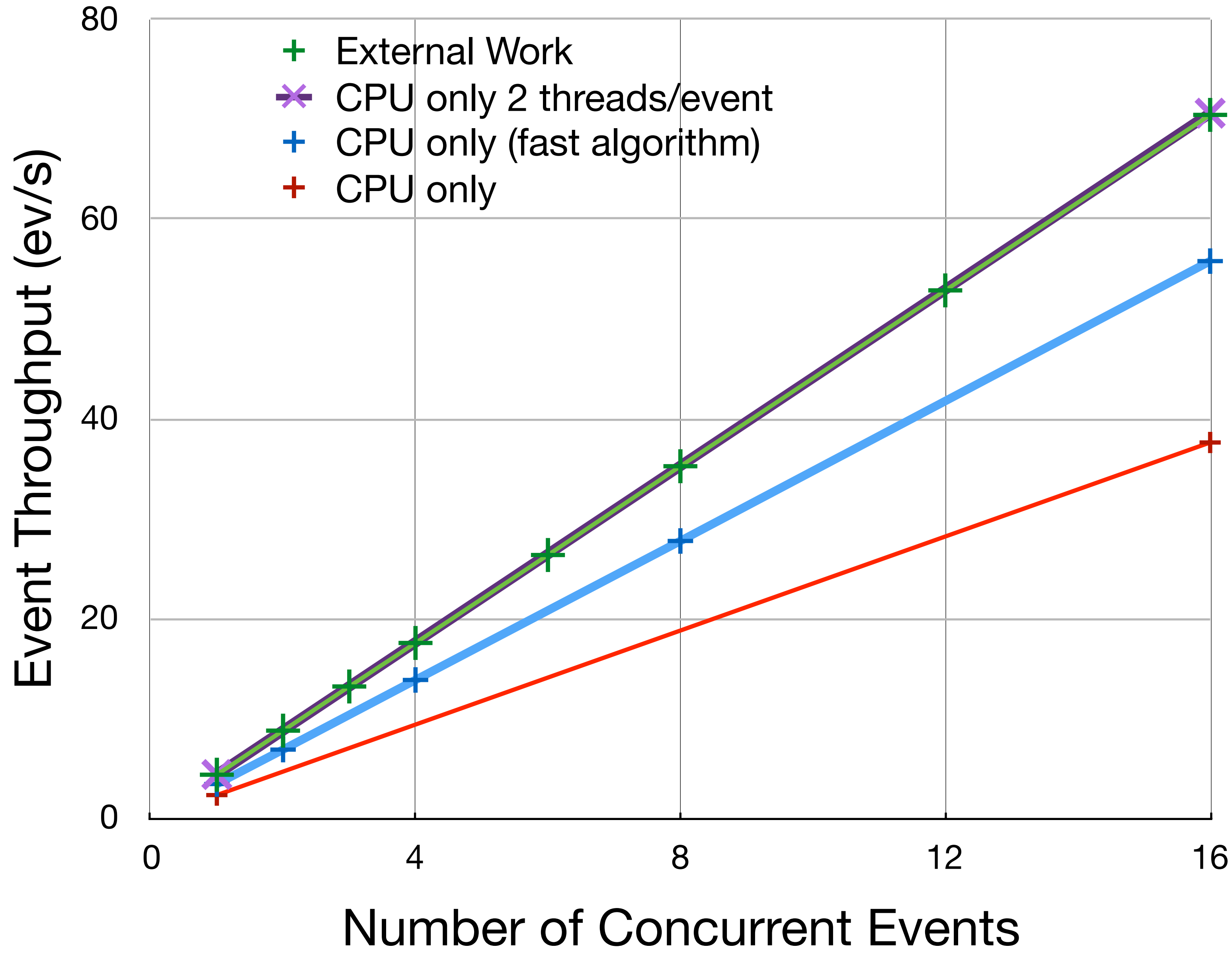


threads = # concurrent events

1 CPU & 1 External Work algorithm



Independent Algorithm Measurements



Have two algorithms that can work in parallel on one event

- **Algorithms take exactly the same amount of time to process an event**

One algorithm can be written to do external work

- **As fast as using two threads per event**

Processing Graph

Stream ID

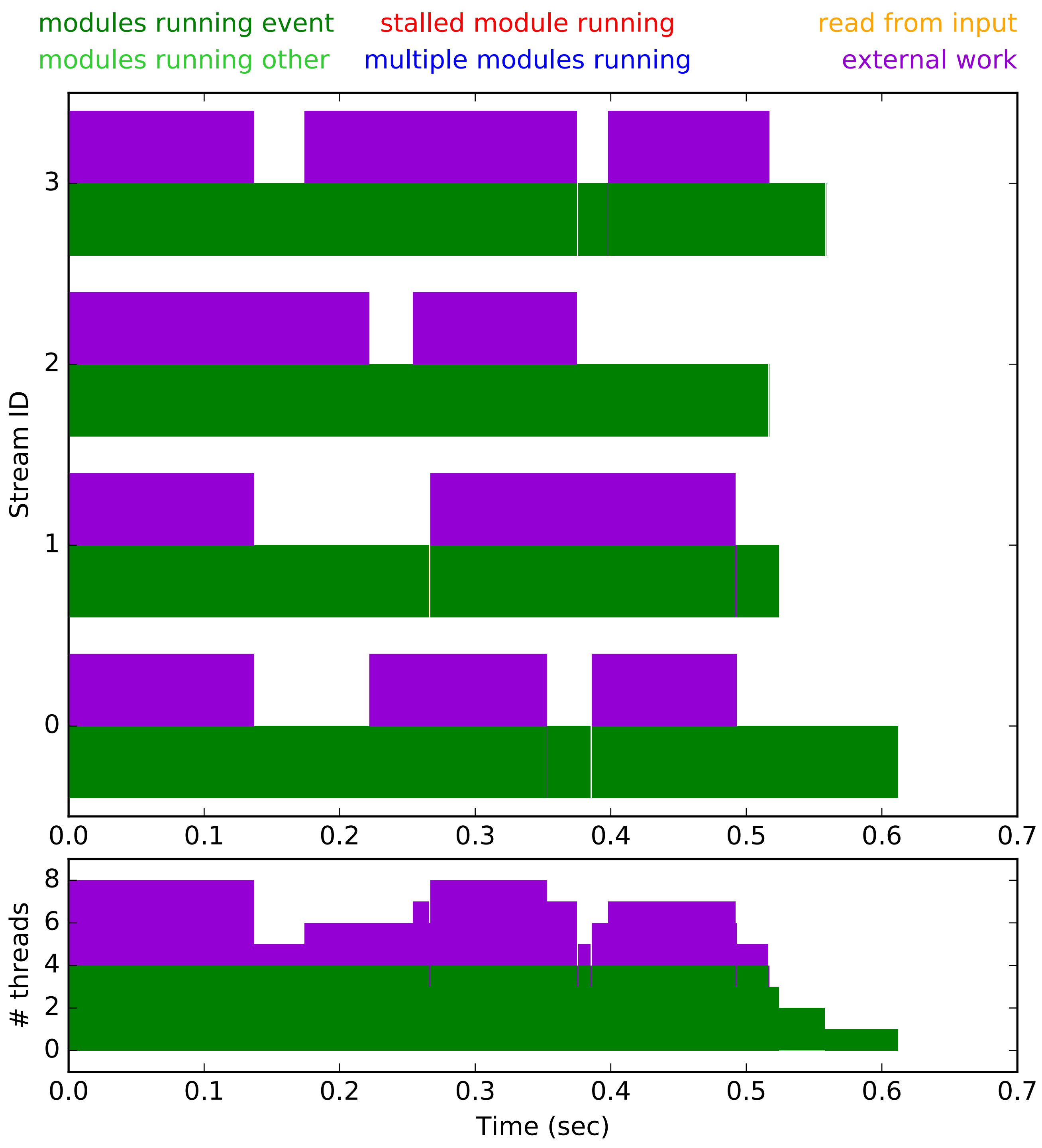
Denotes an independent event loop

Histogram colors

Purple: Work has been passed to the external work controlling thread

- Between *acquire* and *produce*
- Does not mean the work is running

Green: a module is running on a CPU

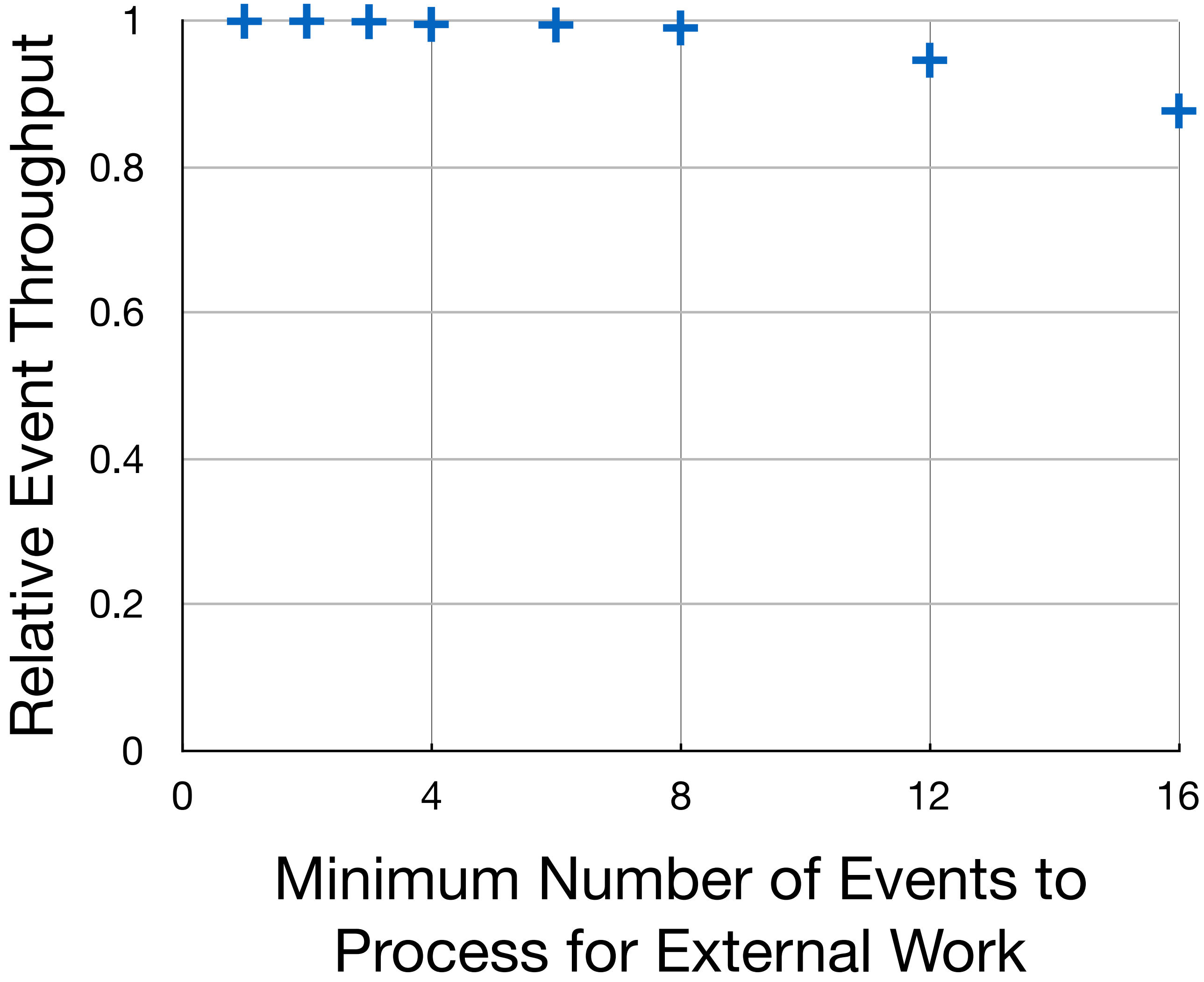


Minimum Number of Events to Process

The external work thread can wait until a set number of events are ready to process

Constants

- 16 concurrent events
- 16 threads

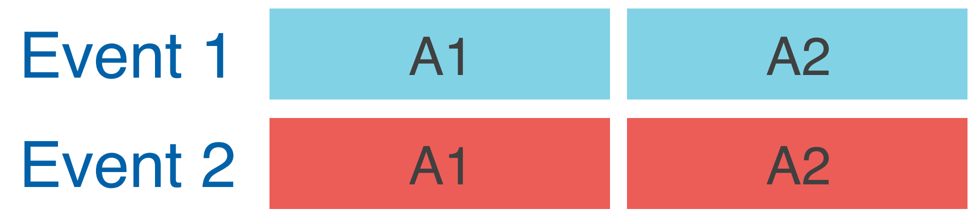


As minimum number of events approaches number of concurrent events the throughput decreases

Expectations for Dependent Algorithms

threads = # concurrent events

both CPU algorithms take same time



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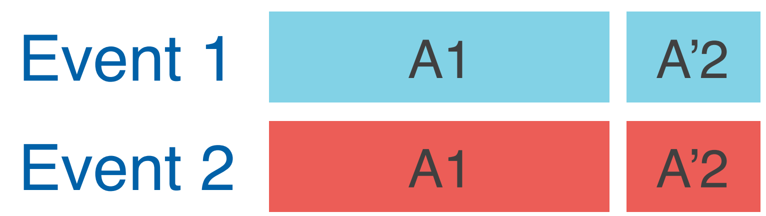
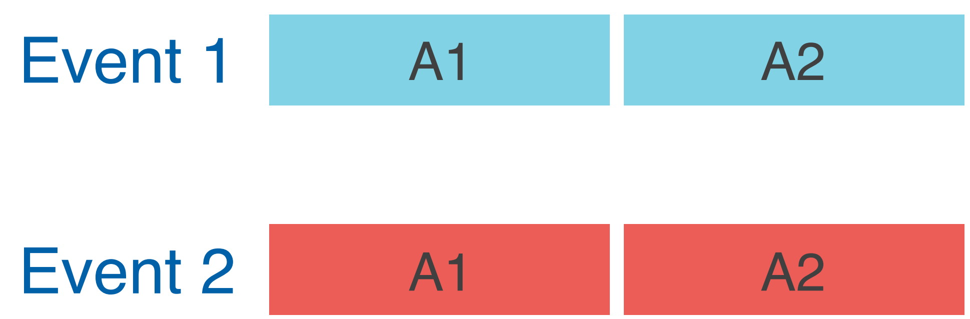


threads = 2 * # concurrent events

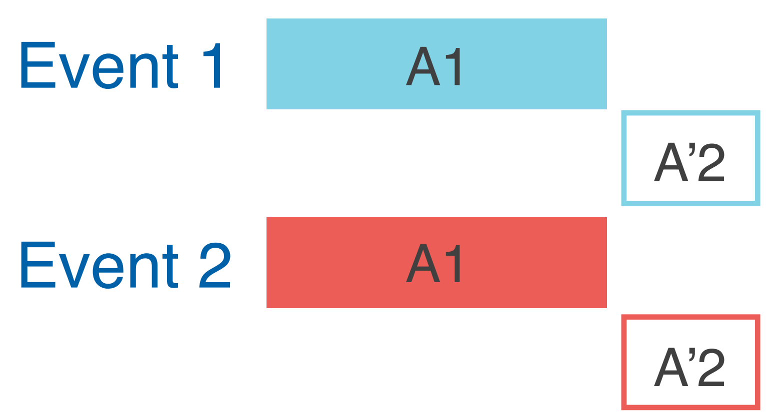
both CPU algorithms take same time

No benefit from extra threads

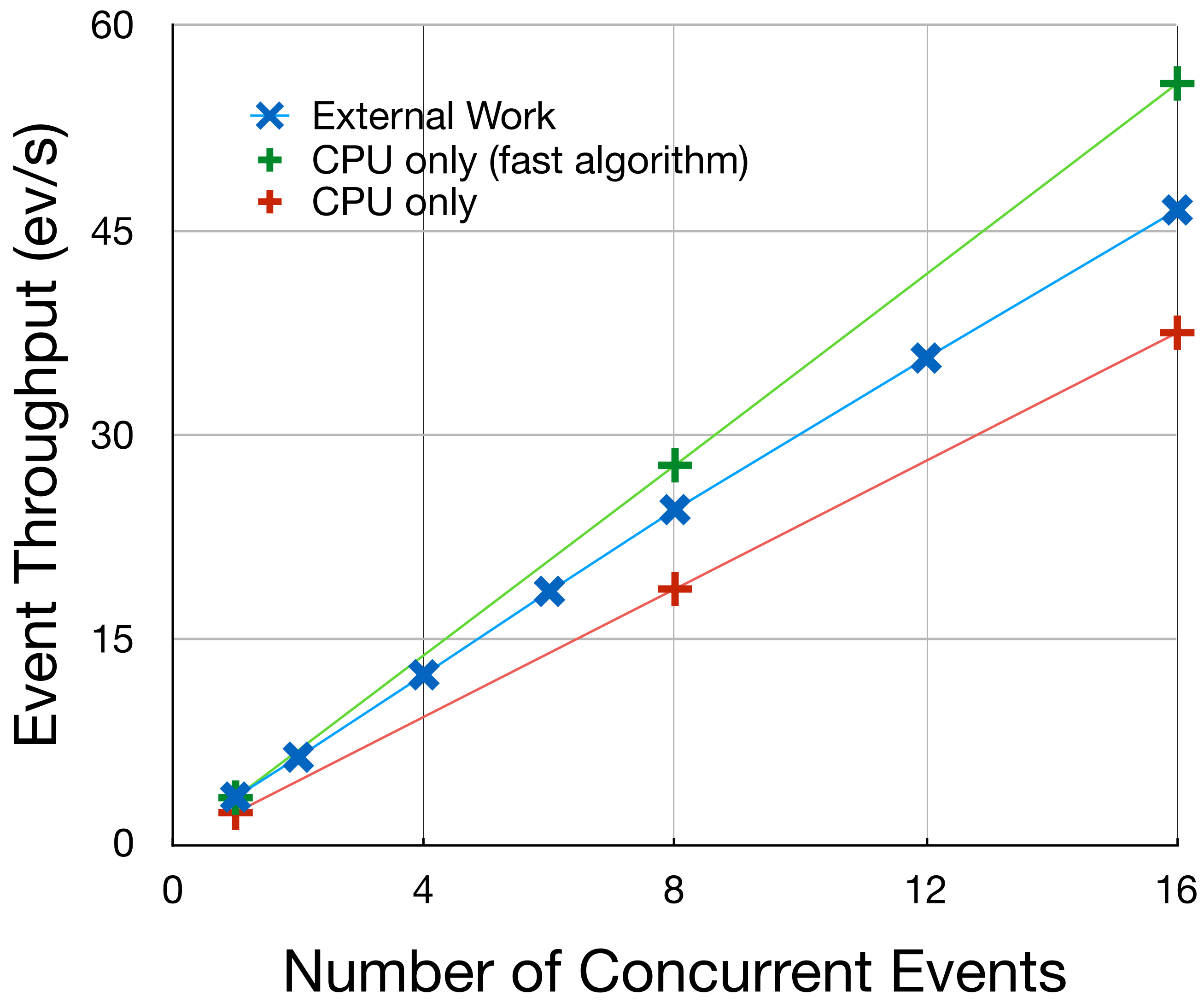


threads = # concurrent events

1 CPU & 1 External Work algorithm



Dependent Algorithm Measurements

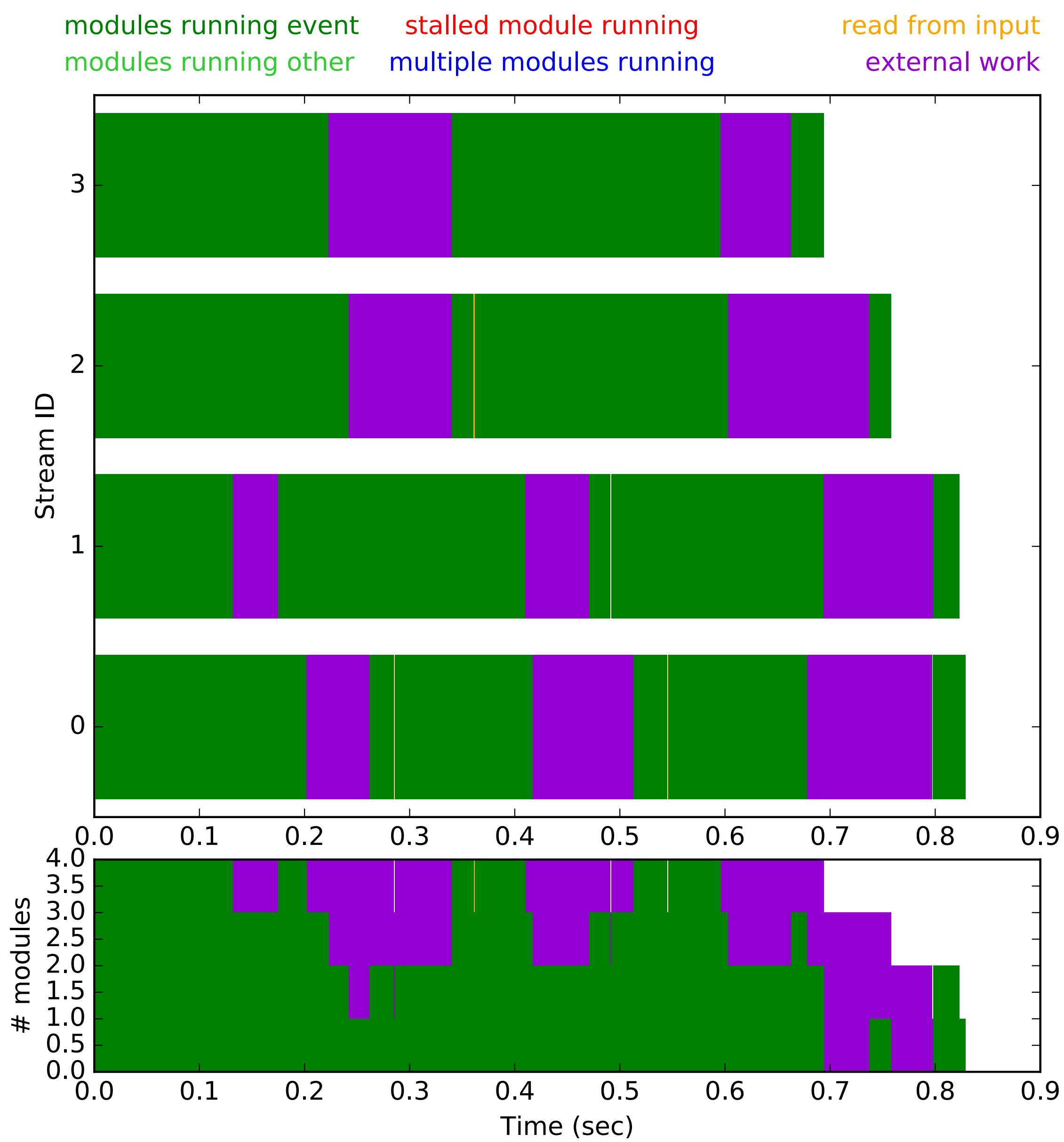


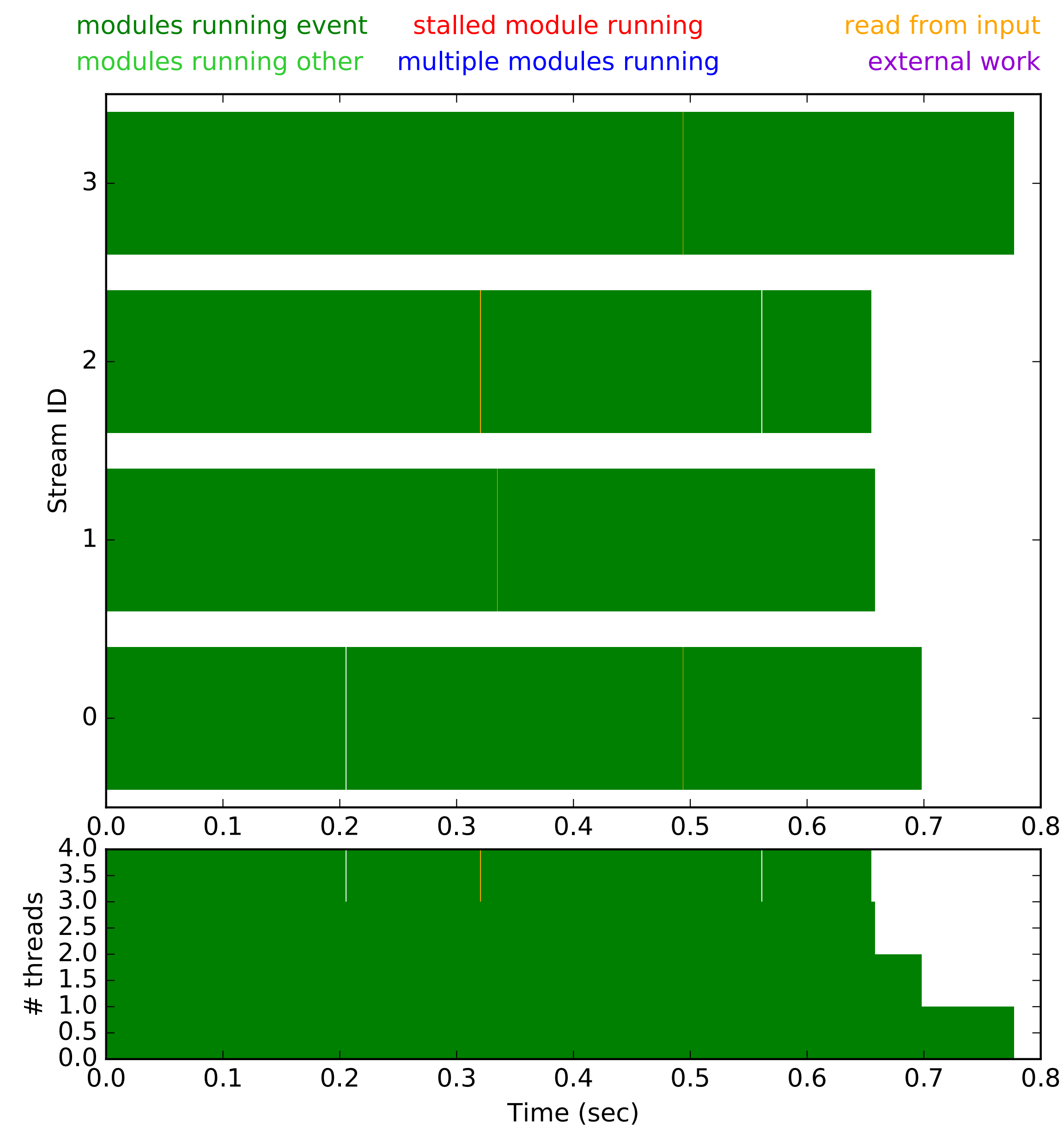
Event processing algorithms must run sequentially

Use of external work is faster than algorithms sequentially

not as fast as if second algorithm ran on CPU as fast as it can on external worker

Dependent Algorithm Processing Graphs

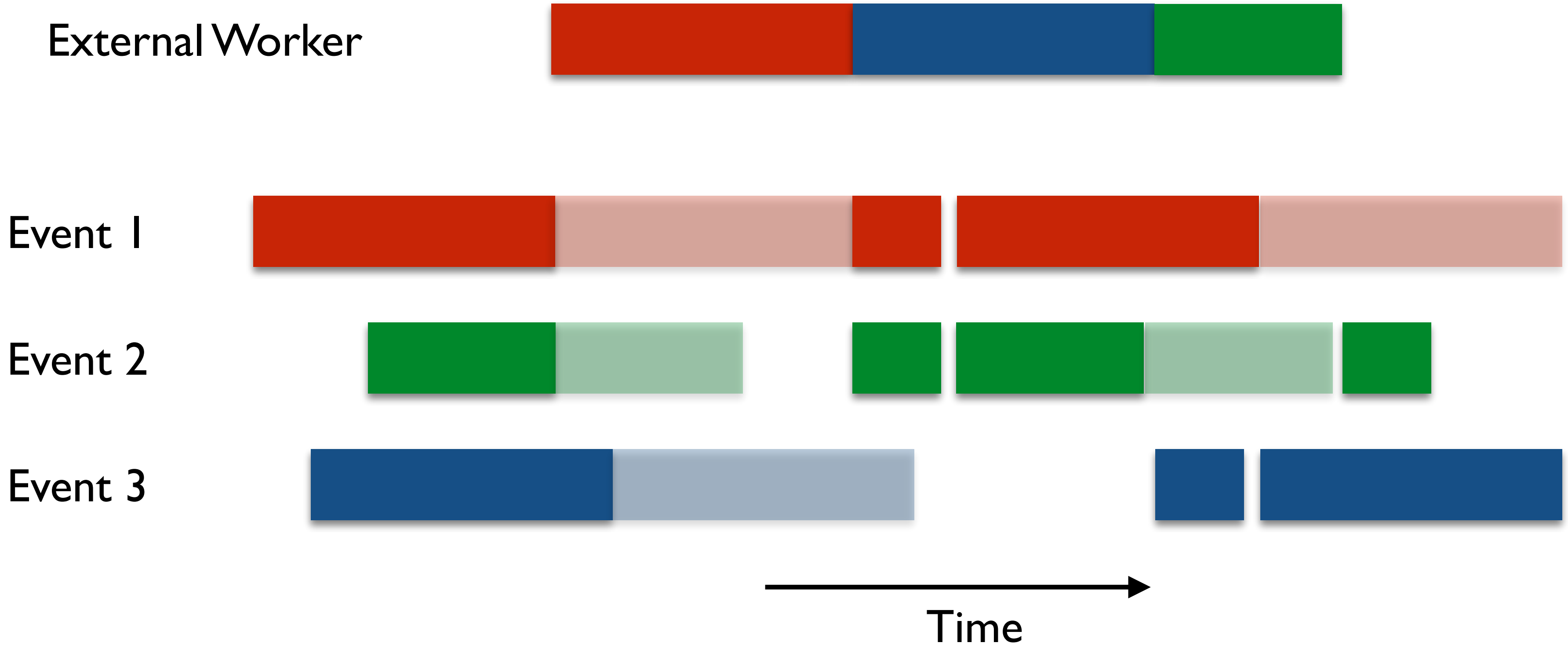




External Work and the CPU module have the same running times

Note the scale change

Cross Event Synchronization



Key
Opaque: Time spent in algorithm/External worker
Semi transparent: amount of time to process data in the External Worker

Can only process 1 work chunk at a time

- **an event must wait for its turn if it missed the most recent start of a chunk**
- **e.g. See Event 3**

External work busy for the longest event time

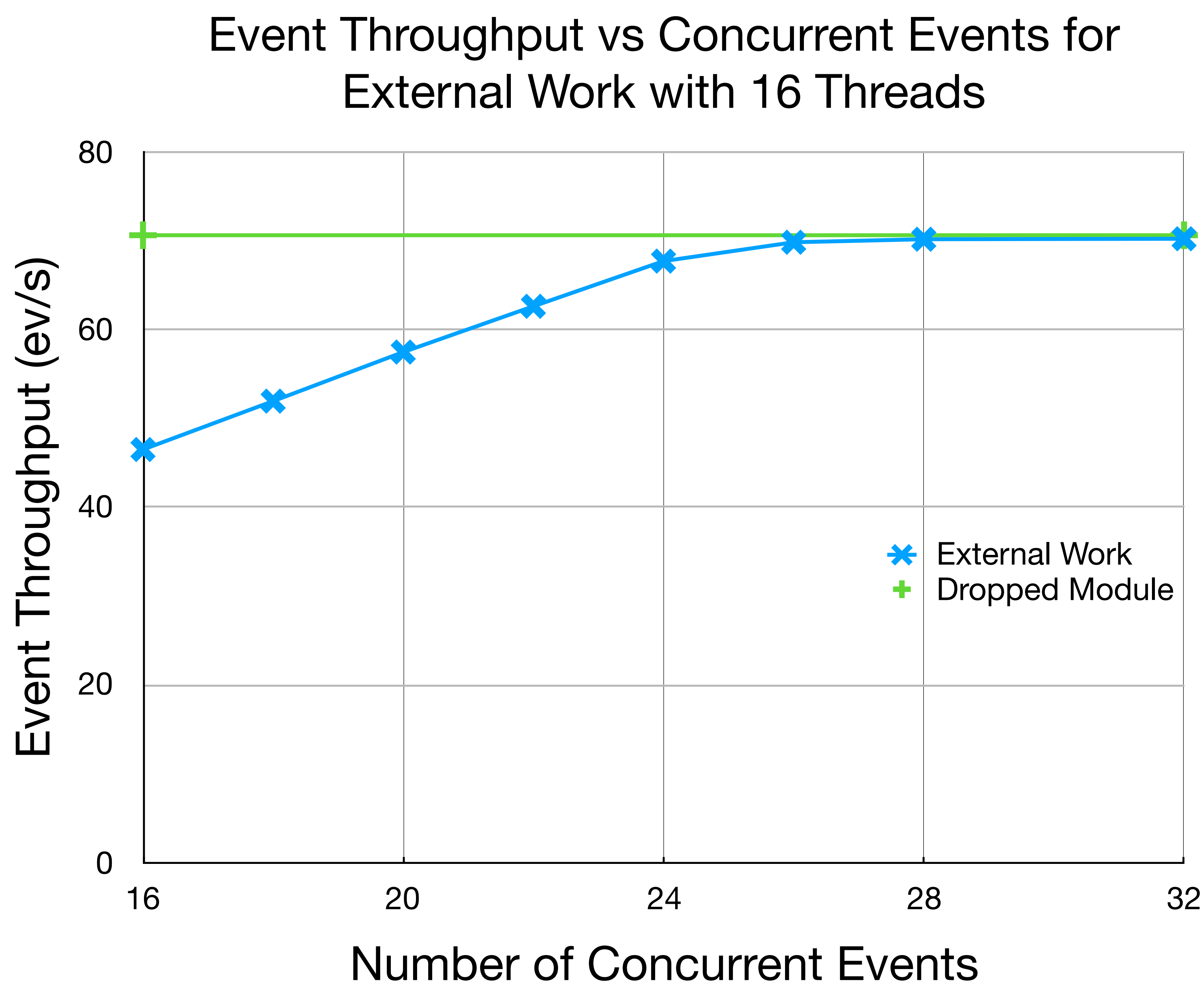
- **events with shorter processing time must still wait for the longer time**
- **e.g. see Event 2**

Number of Concurrent Events > Number of Threads

Use 16 threads

Require external work to only wait for 1 event before processing

With enough concurrent events, can get same result as if the external work module was not in the job



Conclusion

CMS has a mechanism for integrating TBB and accelerators

Exact event throughput benefits dependent on scheduling work to accelerator

- Waiting for enough events to accumulate can decrease throughput

The more intra-event parallelism improves event throughput

- Can schedule work on CPU and accelerator at the same time

May be able to increase event throughput at the cost of extra memory

- allow number of concurrent events to be greater than the number of CPU threads