AthenaMT: Upgrading the ATLAS Software Framework for the Many-Core World with Multi-Threading

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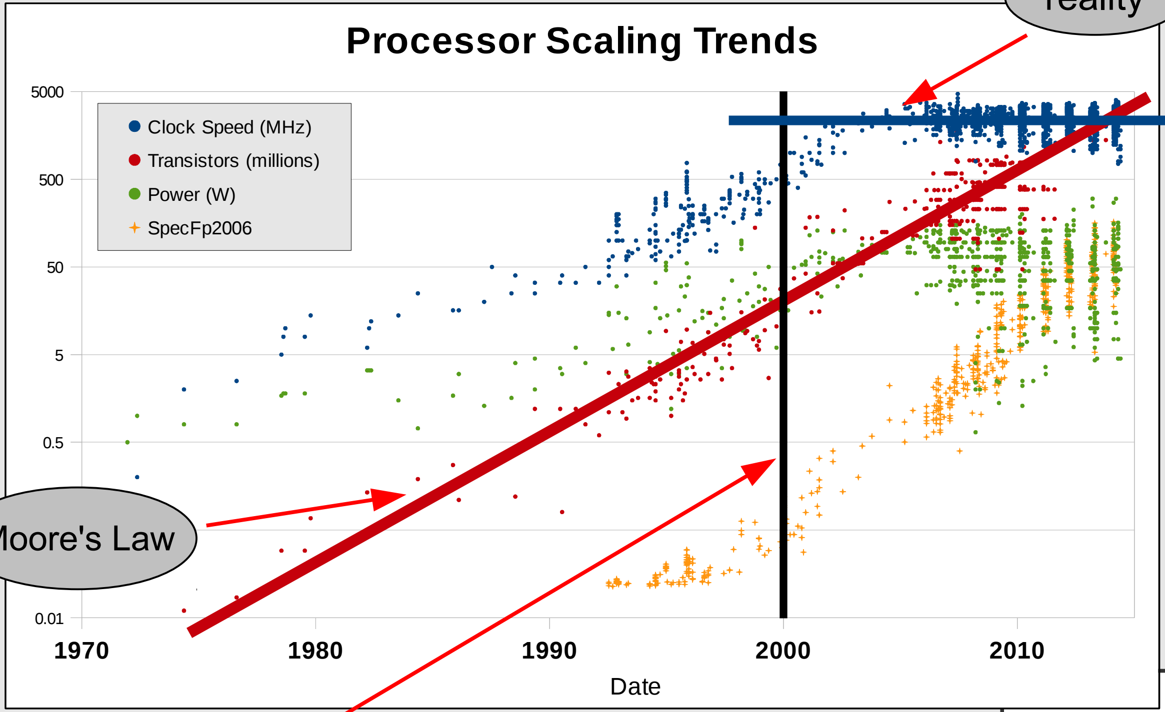
for the ATLAS Collaboration

CHEP 2016

Future Computing Challenges



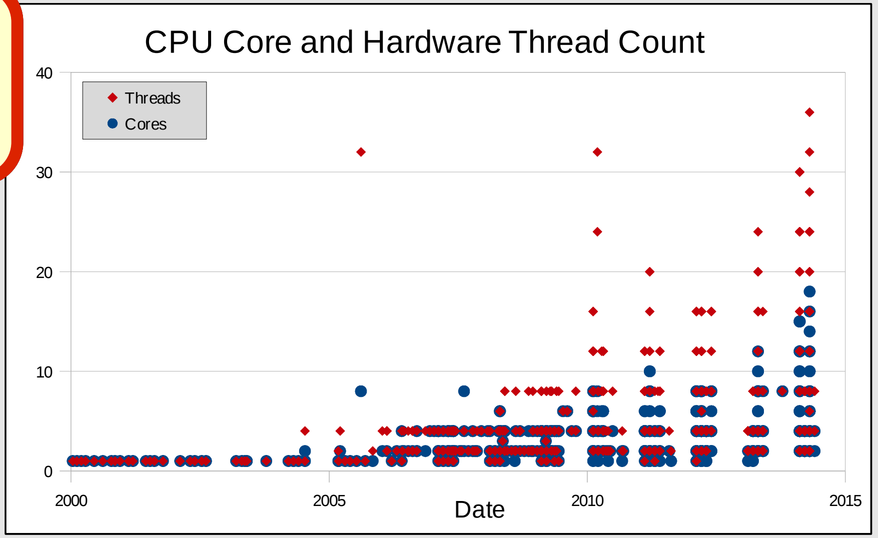
reality

Moore's Law

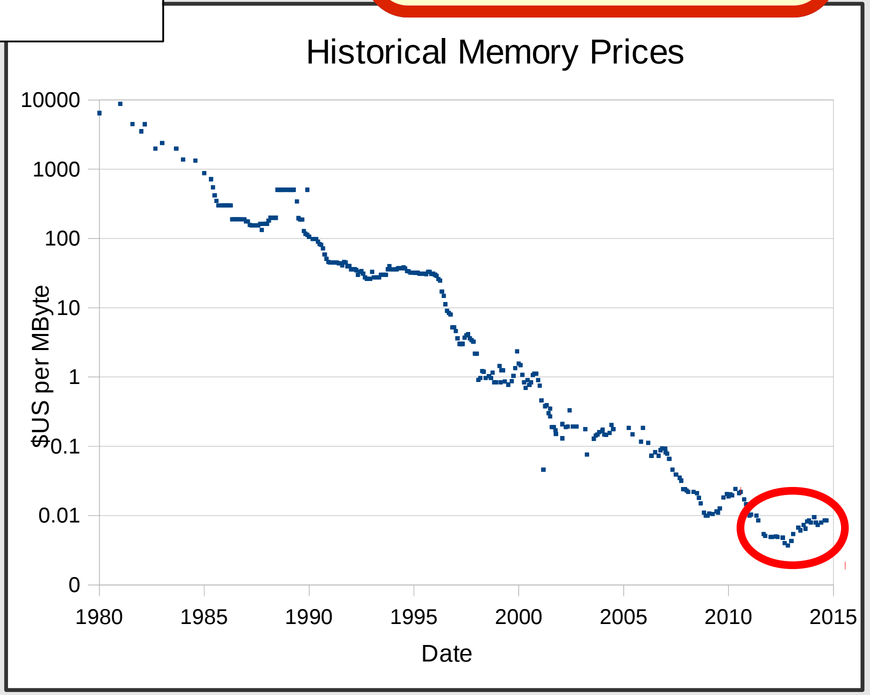
original Gaudi design

CPUs are not getting faster

CPUs are getting wider



memory prices have plateaued



- ATLAS reconstruction uses upwards of 3 GB of memory, more with high luminosity runs
- Cost to equip all grid compute nodes with full memory requirements is more than US$ 6 Million
- Increasing adoption of many-core systems, *eg* Cori, Aurora

Long Term Solution:

Invest in multi-threading

Migration of ATLAS Software to AthenaMT

Date	Framework	Algorithms
2015	Event Store access via Data Handles; Event View design completed; Updated Configuration design; Re-integration of Hive features into Gaudi trunk	Few Algorithms as concurrent prototypes, concentrate on high inherent parallelism; general clean-up of code
2016 Q2	Event Views implemented; IO Layer redesigned; Core Gaudi service migration starts	Wider set, prototype CPU expensive Algs with internal parallelism
2016 Q4	Parallel Algorithm support; Detector/Condition Store re-implementation; Schedulable Incidents; Main Athena development branch moved to Gaudi trunk	First trigger chains running with Event Views; limited reconstruction
2017	All Athena and Gaudi Services made thread safe; Support for re-entrant Algorithms	Serious migration with select groups; Core of useful Algorithms to allow for framework optimization
2018	Framework optimization, and tuning for different hardware	Bulk of Algorithm migration
2019		Integration and Readiness for Run 3

- Aggressive schedule
  - many migrations steps are not parallelizable
- On track for most milestones
  - but not all!

- Will focus on what we've accomplished in 2016

Enabling Concurrency for Core Services

- Majority of hard work in migrating ATLAS code to AthenaMT is in making shared Services thread safe or able to handle multiple concurrent events.

- Some Services can be made concurrent / thread safe with simple mutexes or thread safe data structures

- Some need more modifications to handle state information of multiple concurrent events
  - `MagFieldSvc`: carry event specific cache along with each request
  - `THistSvc`: users can choose whether to share or clone histograms
    - thread safe access to shared histograms via smart locking handles

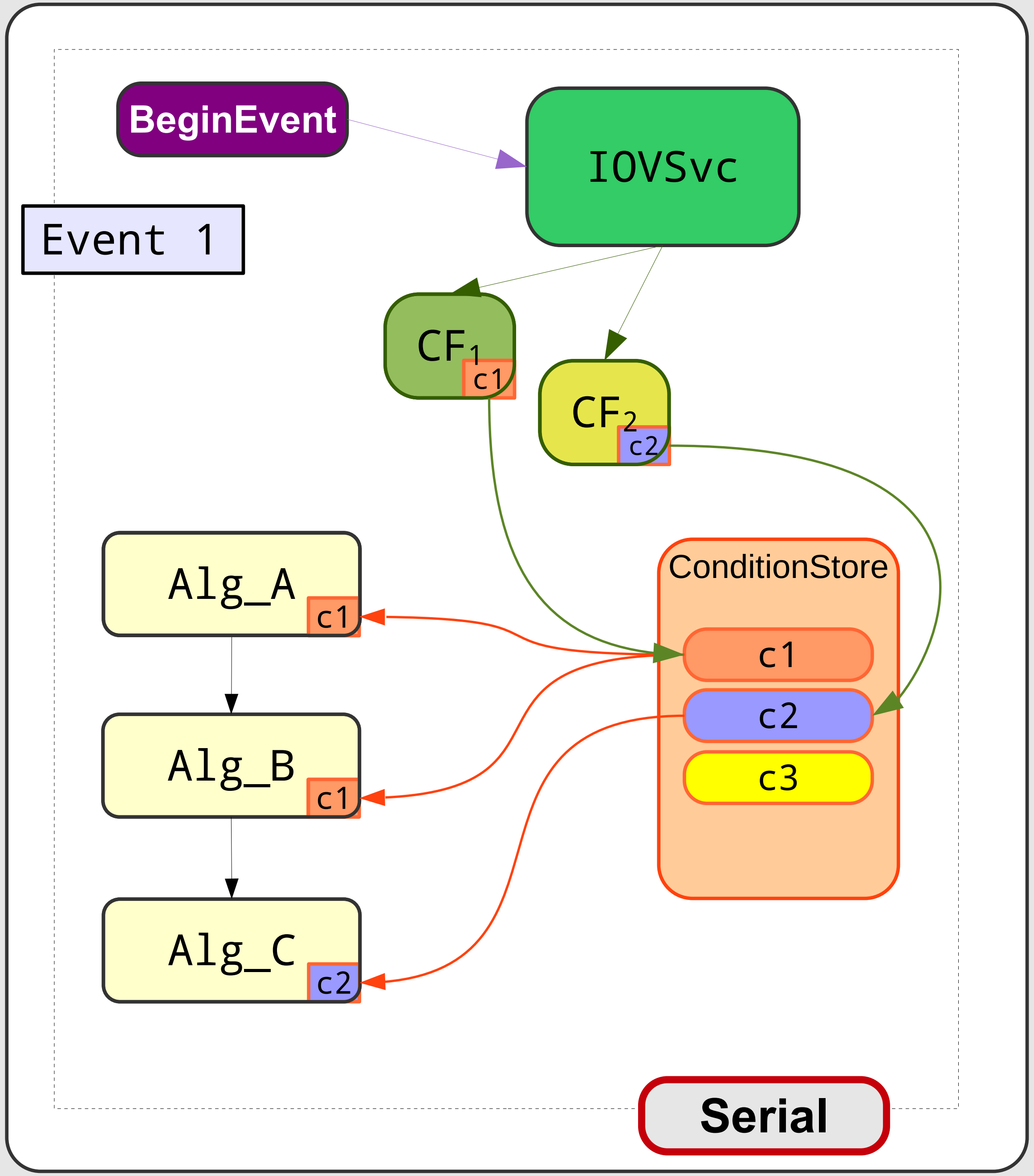
- Some need complete redesign
  - Conditions / `IOVSvc` (Intervals of Validity) / `GeoModelSvc` (Detector Alignment)
  - `IncidentSvc`

Concurrent Processing of Asynchronous Data

- **Conditions**
  - *eg* high voltages, calibrations, *etc*
- **Detector Geometry and Alignments**
  - *eg* position changes

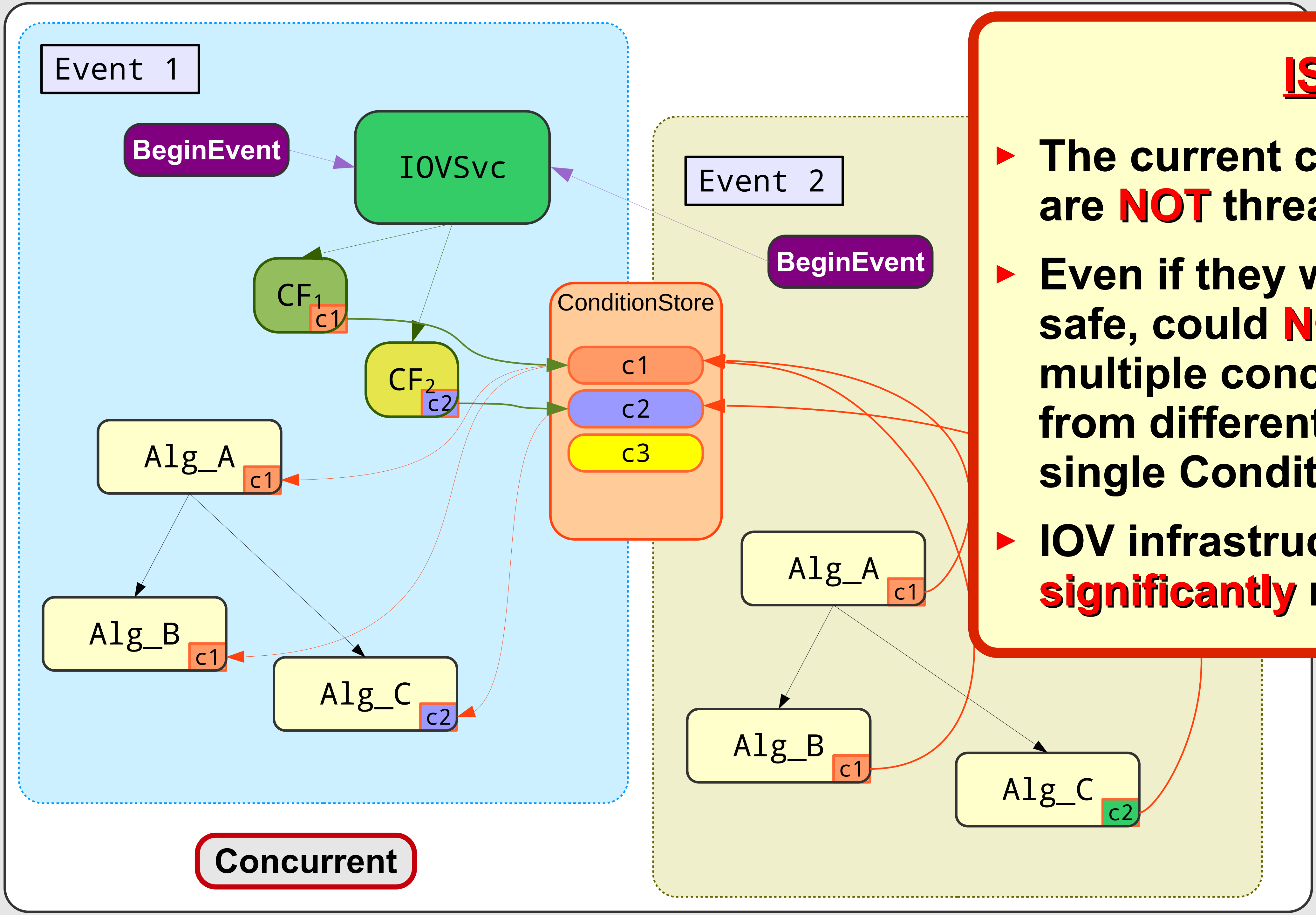
- **Requirement**: Minimize changes to client code
  - there's lots and lots of it!
  - avoid forcing Users to implement fully thread-safe code by handling most thread-safety issues at the framework / Services level (without compromising concurrency)
- **Requirement**: All access to Event data is *via* smart **DataHandles**, which also declare data dependency relationship to the framework
  - we can use this by implementing **ConditionHandles**
    - do all the heavy lifting inside the Handle

Serial Processing with Conditions



- All framework elements process data from the same **I**nterval **O**f **V**alidity
- Algorithms are blind to the IOV, and retrieve data from the **ConditionStore**
- At the start of every Event, **IOVSvc** checks IOVs, and triggers any necessary updates
  - handled by the Callback Functions
  - Callback Functions are **shared** instances
- Only one copy of any Conditions object is maintained in the Store

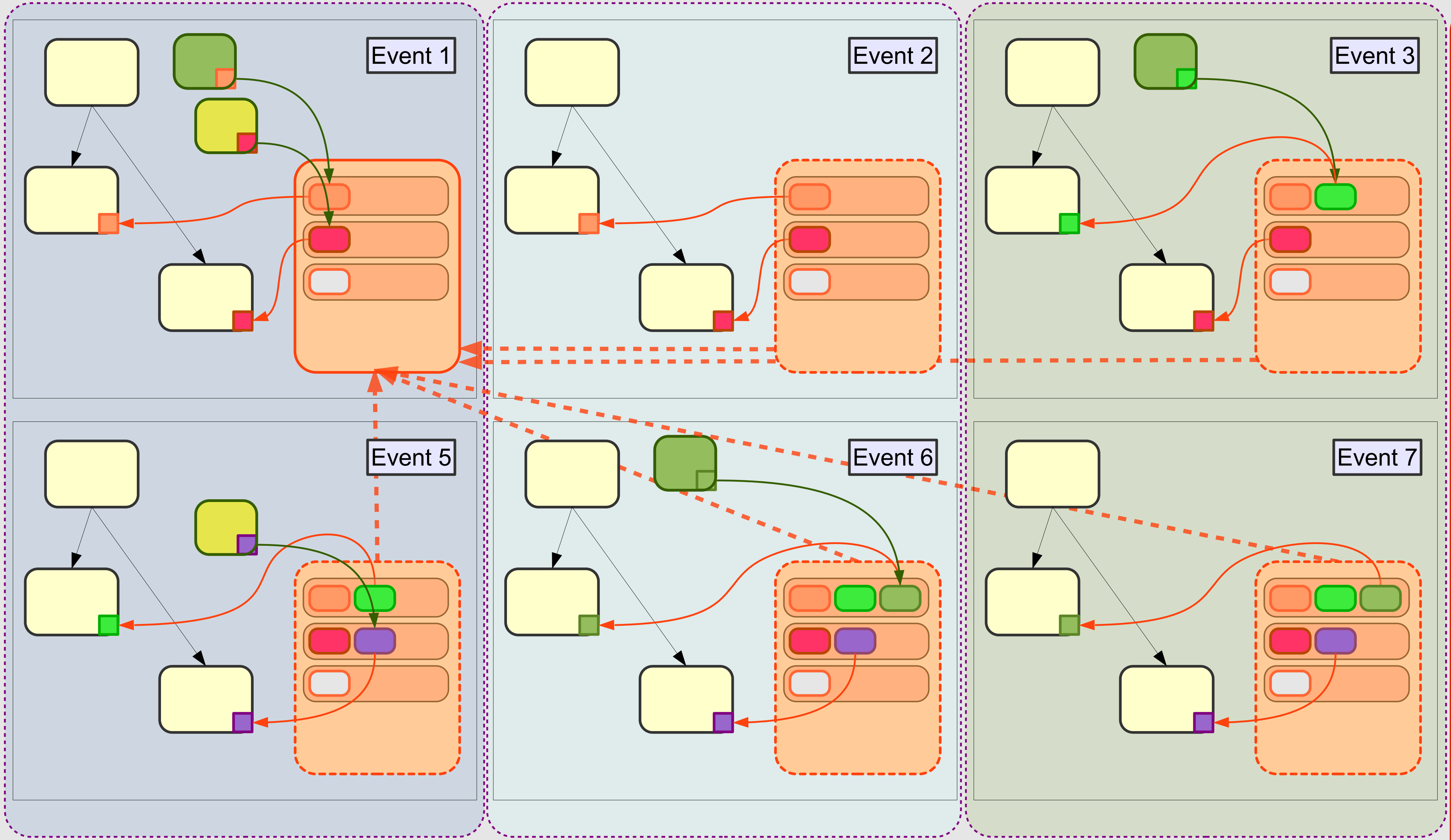
Concurrent Processing with Conditions



ISSUES

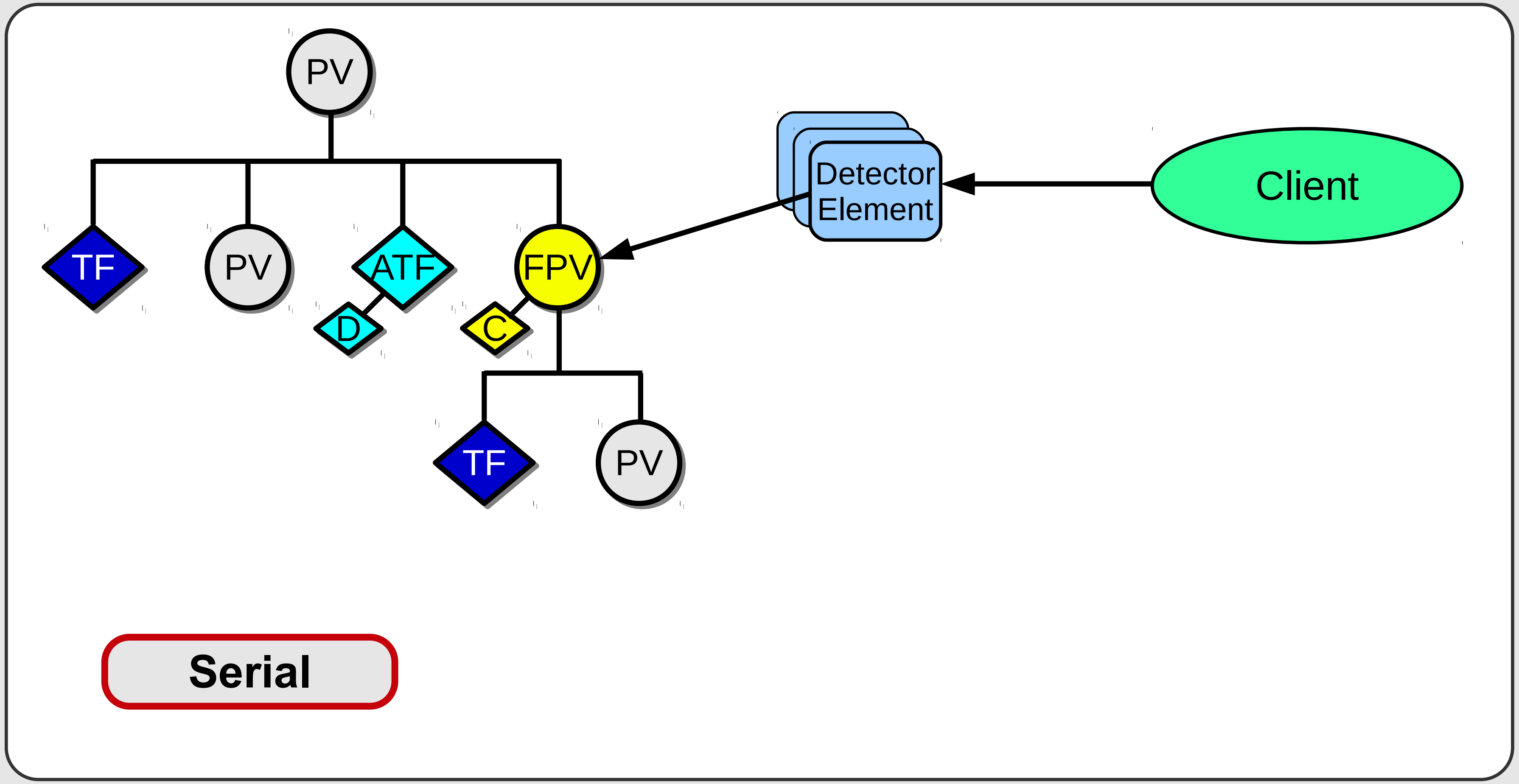
- The current callback functions are **NOT** thread-safe
- Even if they were made thread-safe, could **NOT** run with multiple concurrent Events from different IOVs due to the single ConditionStore
- IOV infrastructure needs to be **significantly** modified for MT

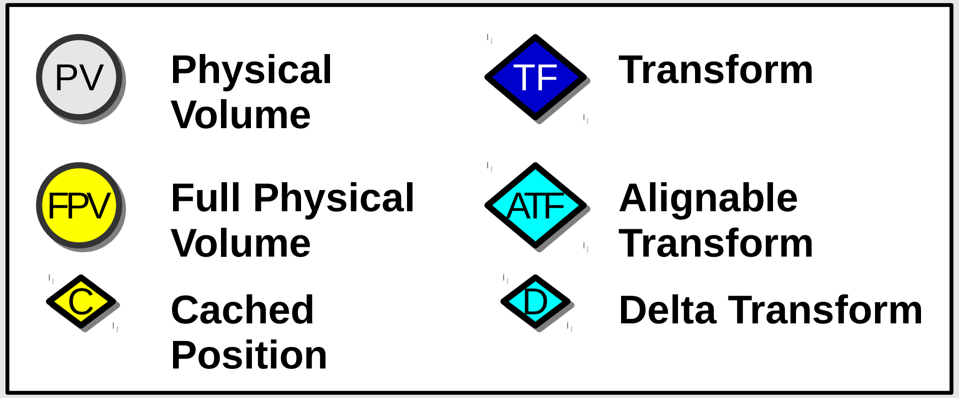
Concurrent: Single Multi-Cache Condition Store



- **One** ConditionStore, shared by all Events.
  - no wasted memory
  - no duplicate calls
  - Store elements are **ConditionContainers**, with one entry per IOV
- Data access via **ConditionHandles** that point to appropriate entry
- Callback Functions become **Algorithms**, scheduled by framework

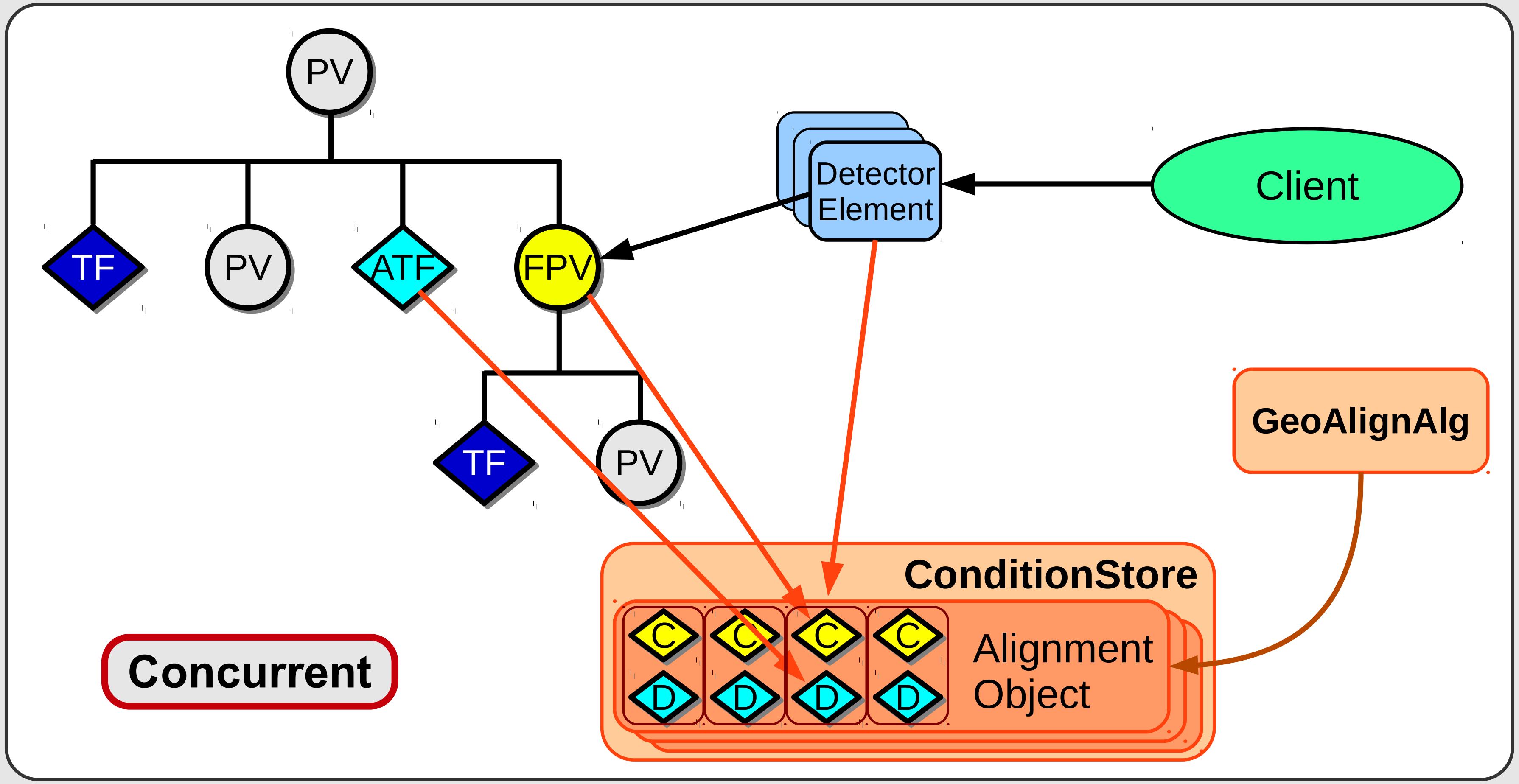
Geometry Alignments in AthenaMT

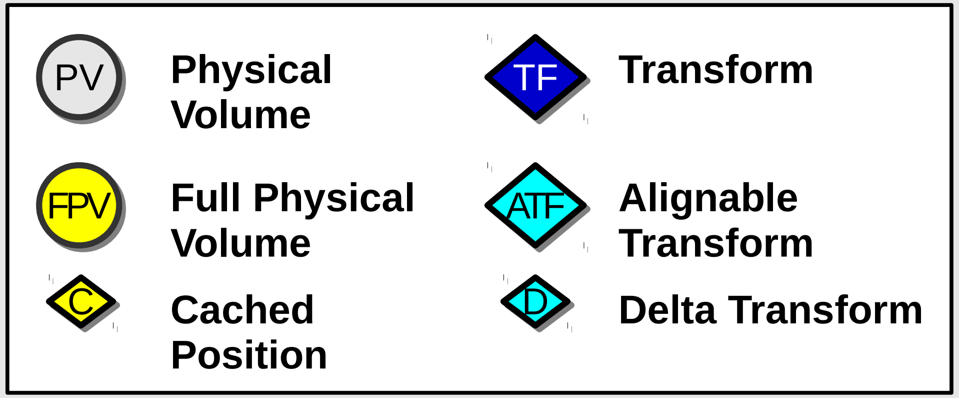




- Detector Element position cached in **Full Physical Volume**
  - built from a **Physical Volume** description, a **Transform**, and a time dependent **Alignable Transform** that reads a **Delta** from a database
- Not functional with concurrent events that have different Deltas and associated caches

Geometry Alignments in AthenaMT

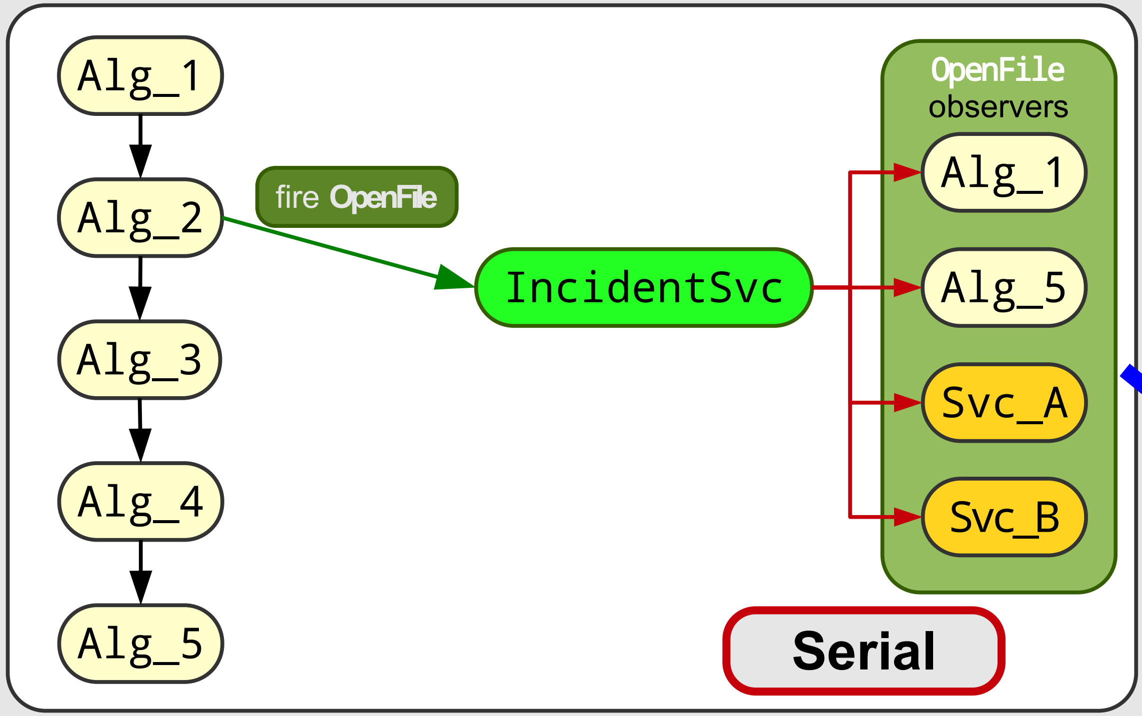




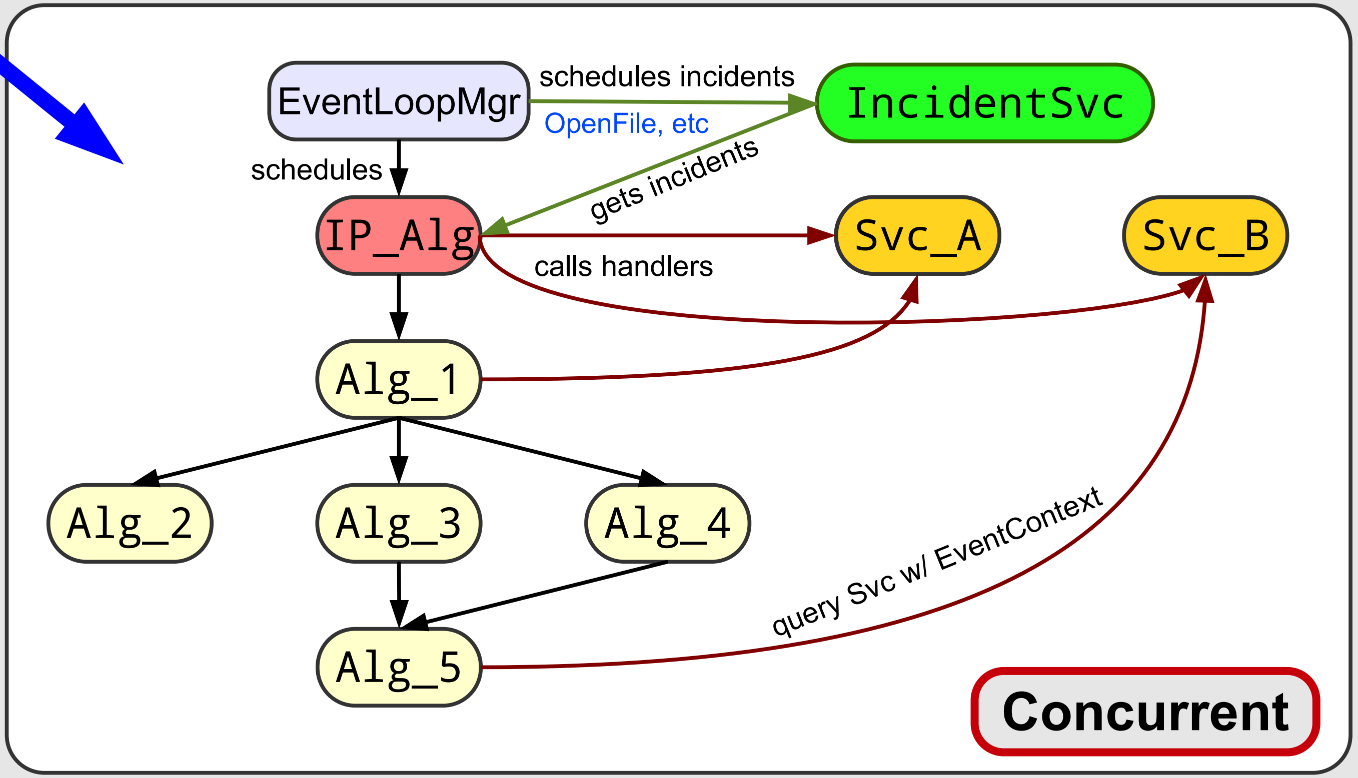
- Encapsulate alignment deltas and cached positions in AlignmentObjects that reside in the ConditionStore
  - accessed via ConditionHandles
  - updated on demand via a scheduled GeoAlginAlg
- Clients of DetectorElements are completely unaware of migration

IncidentSvc in AthenaMT

- **IncidentSvc**: manages asynchronous callbacks for clients using an Observer pattern



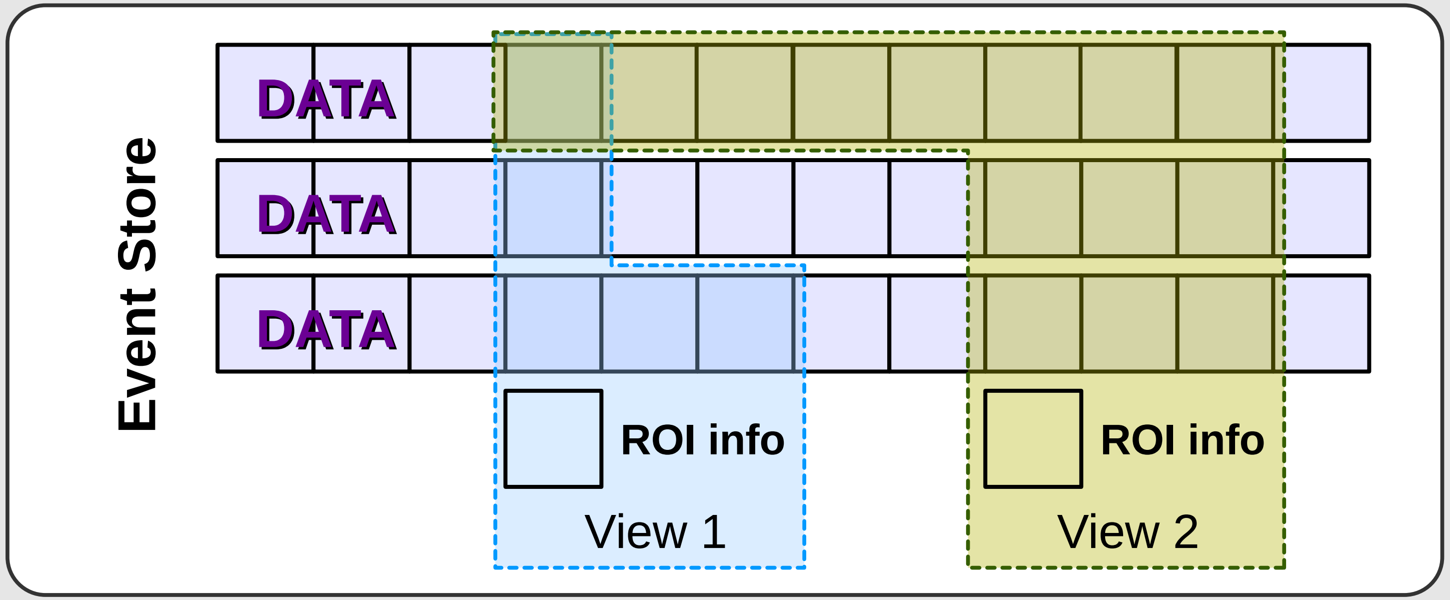
- **Study**: design is far more flexible than actual usage
  - mostly fired **outside** of the Algorithm processing loop



- **Solution**: **limit scope**: Incidents can be re-classified as discrete state changes
  - Incidents become **schedulable**, managed by framework
  - Incident handlers / observers become discrete Algorithms, that interact with EventContext aware Services

Event Views and DataHandles

- For performance reasons, the High Level Trigger operates on geometrical Regions of Interest (ROI)
- Since all Algorithms access Event data via smart DataHandles, they can be run unmodified in a ROI simply by having the framework modify the DataHandle itself
- Implemented an `EventView` class that can be used interchangeably with the whole event store. Each View is populated with data corresponding to a single ROI
  - Each EventView has the same interface as the whole event store
  - Contain Data Objects that describe the corresponding ROI
  - Allow for potential alternative use-cases



see presentation by Ben Wynne on Tuesday at 2PM for further details

Re-Entrant Algorithms

- Cloning of Algorithms in GaudiHive allows us to avoid most thread safety issues
  - clones can run concurrently with different Event Contexts without interference
  - have to avoid "thread hostile" behaviour
    - global statics
    - back channel communications
  - some Algorithms can't be cloned – scheduling bottleneck

- Downside of many clones is increased memory use
  - can limit number of clones, at the expense of limiting possible concurrency

- Added support for re-entrant Algorithms
  - only one instance
  - can be executed simultaneously in multiple threads in different Events
  - **MUST** be thread safe
    - enforced with new base class and `Algorithm::execute_r() const` signature
  - envision limited usage for special purpose tasks, written by experts

Summary

- ATLAS has begun the migration of core framework elements that require the most significant design changes beyond mere thread safety
  - sometimes by completely re-evaluating functionality and limiting design to actual use cases
- We have made design choices that minimized alterations to client code
  - leverage existing features of framework, *eg* DataHandles and the Scheduler
- Changes to Algorithmic client code that use these elements are also underway
  - relatively straight forward recipe for the most part (but a lot of grunt work)
- Anticipate on-schedule finalization of design, and implementation of essential core Services by end of 2016, with full support of MT concurrency by end of 2017
  - we already have production level Atlas G4 simulation running in MT on KNL.

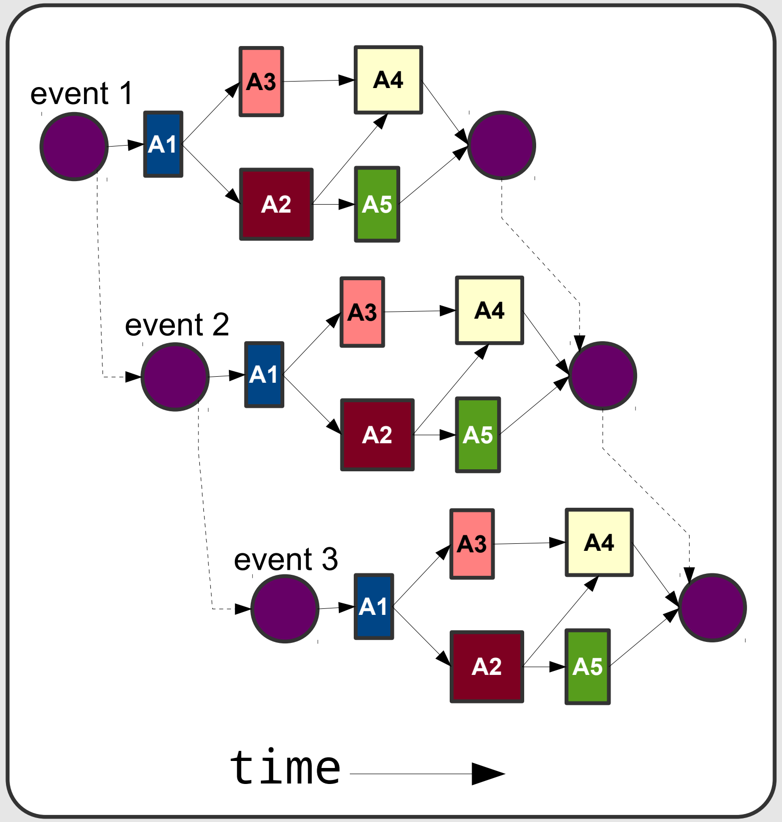
see Steve Farrell's talk Thursday, track 2, 2PM

- Broad migration of Algorithm code to use these features will begin in 2017

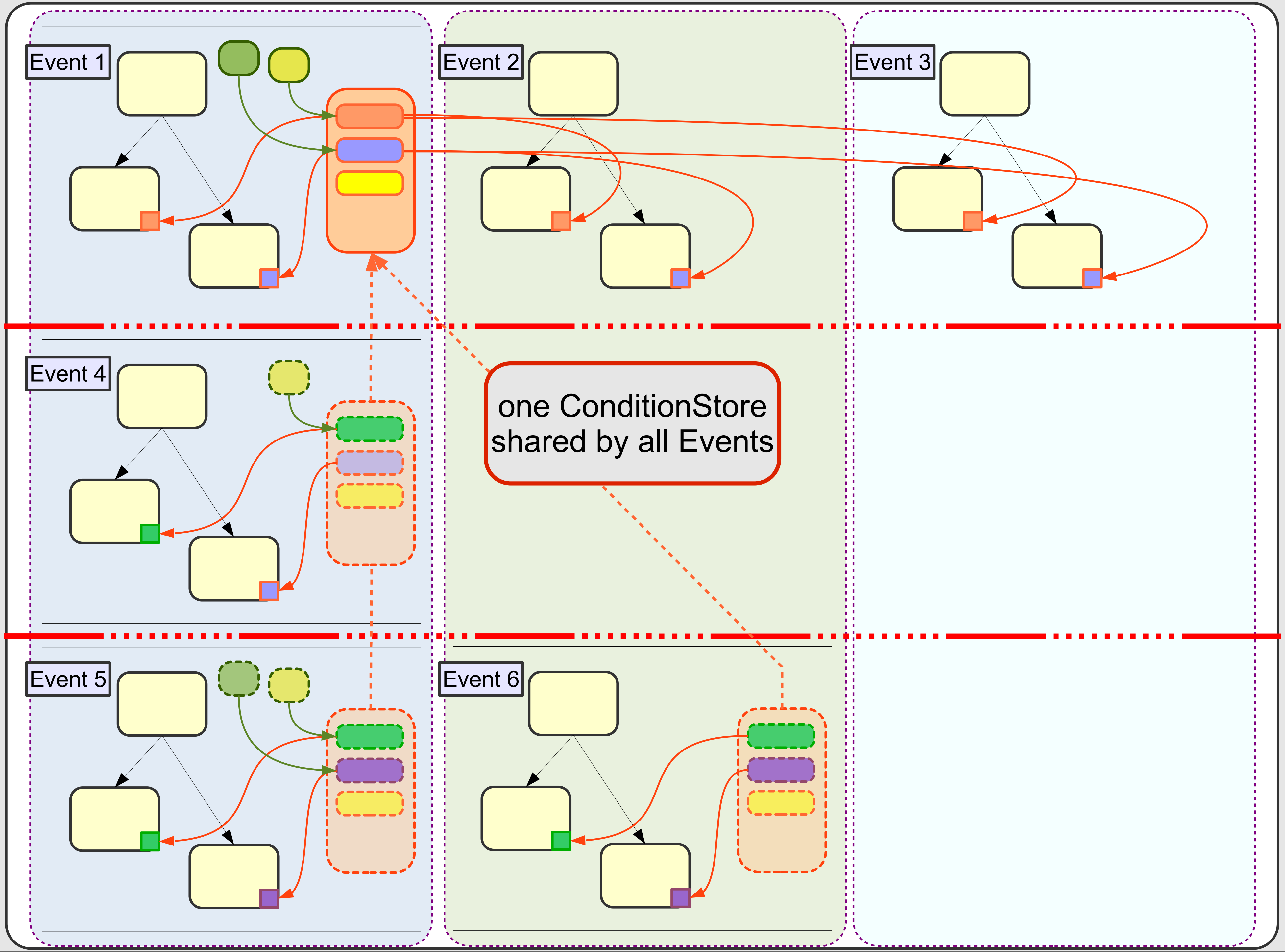
Extras

AthenaMT / Gaudi Hive

- AthenaMT: based on Gaudi Hive: multi-threaded, concurrent **extension** to Gaudi
- Data Flow driven
  - Algorithms declare their data dependencies
  - Scheduler automatically executes Algorithms as data becomes available.
    - optimal traversal of graph possible if avg. Algorithm runtimes known
- Multi-threaded
  - Algorithms process events in their own thread, from a shared Thread Pool.
- Pipelining: multiple algorithms and events can be executed concurrently
  - some Algorithms are long, and produce data that many others need (eg track fitting). instead of waiting for it to finish, and idling processor, start a new event.
- Algorithm Cloning
  - multiple instances of the same Algorithm *may* exist, and be executed concurrently, each with different Event Context.
    - **legacy** : one instance, non-concurrent
    - **cloneable** : one or more instances, in its own thread
    - **re-entrant** : once instance, executed concurrently by multiple threads
- Thread Safety
  - Only shared Services and re-entrant Algorithms need to be thread safe
  - Algorithms must avoid thread-hostile behaviour
    - global statics, etc



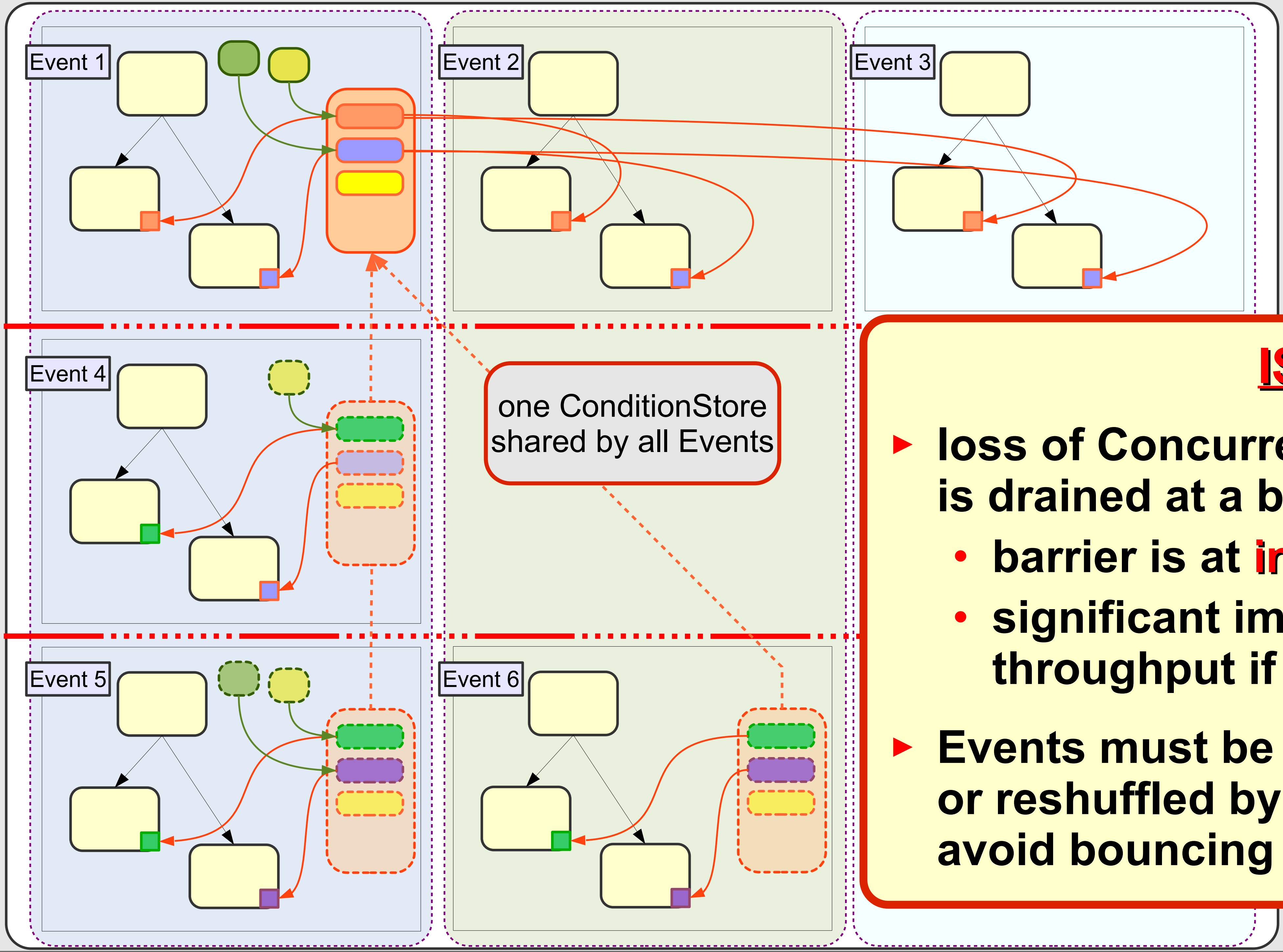
Concurrent: Scheduling Barrier



Scheduler can only **concurrently** process events which have **all** Conditions in the **same** IOV

NO changes required in User code and minimal changes in IOV code

Concurrent: Scheduling Barrier



Scheduler can only **concurrently** process events which have **all** Conditions in the **same** IOV

ISSUES

- **loss of Concurrency when Scheduler is drained at a barrier**
  - **barrier is at intersection of all IOVs**
  - **significant impact on Event throughput if IOVs change often**
- **Events must be processed in order, or reshuffled by the Scheduler to avoid bouncing back and forth**

ConditionHandles