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drift chamber multithreaded simulation with Gaudi Hive

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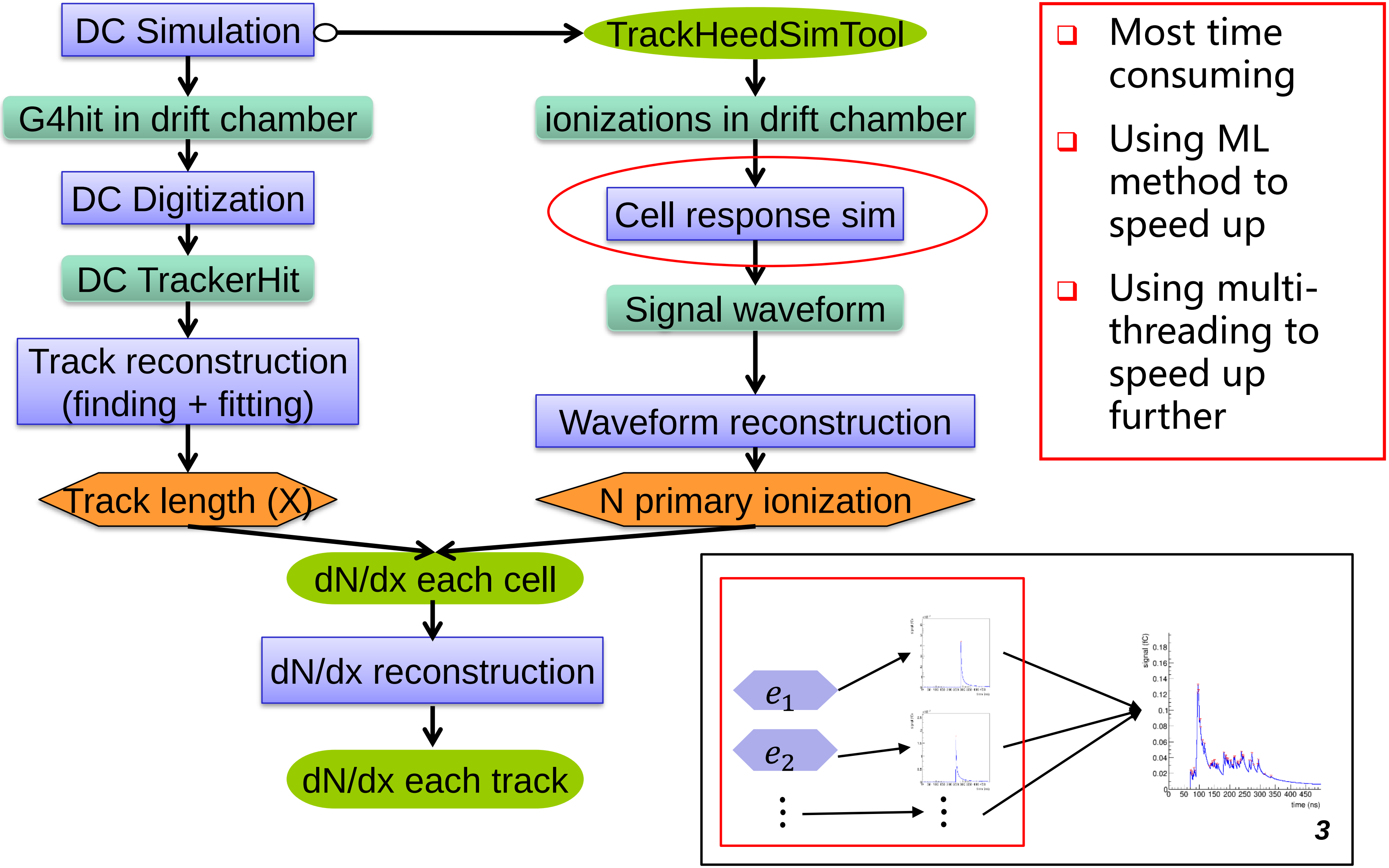
Motivation

- CEPC is a precise experiment
  - Higgs, W, Z, …
  - PID performance is important
- From previous study, the primary ionization counting (dN/dx) method has potential to get very good PID performance (<3% resolution)
- To prove that, the dN/dx method will be detailed studied for CEPC drift chamber. Need precise dN/dx simulation

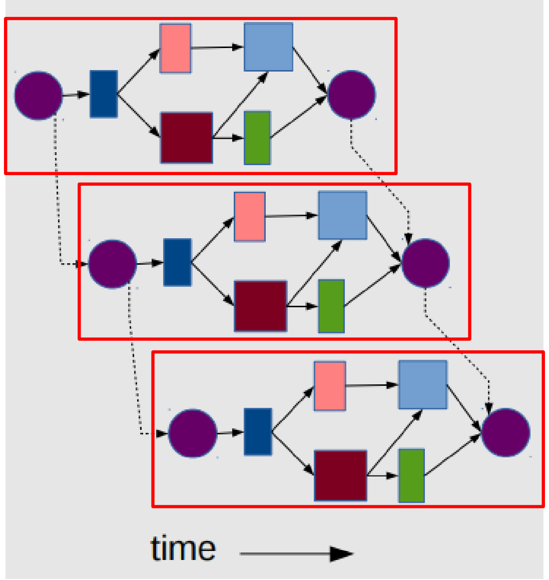
Schema of dN/dx study in CEPCSW



- ❑ Most time consuming
- ❑ Using ML method to speed up
- ❑ Using multi-threading to speed up further

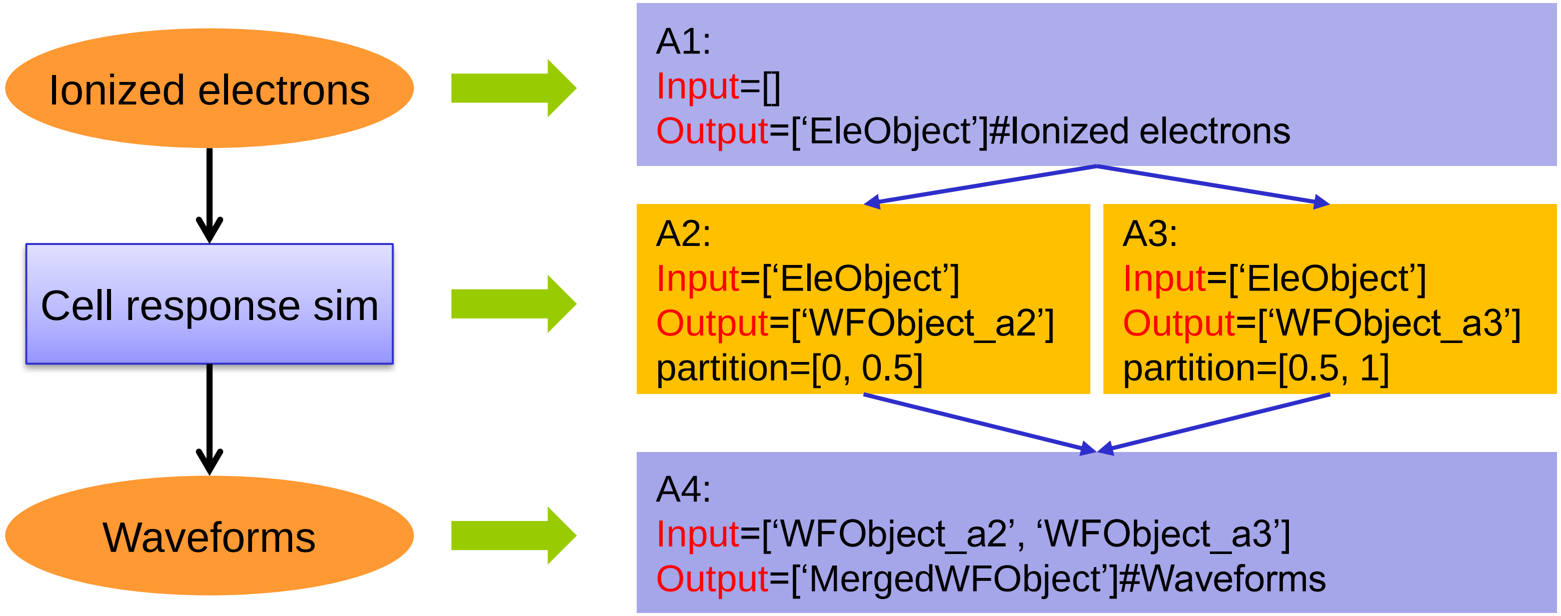
Gaudi Hive

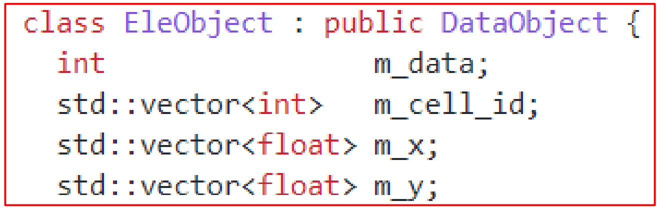
- Gaudi Hive: multi-threaded, concurrent extension to Gaudi
- Data Flow driven mechanism
  - Algorithms declare their data dependencies
    - build a directed acyclic graph - can be used for optimal scheduling
  - Scheduler automatically executes Algorithms as data becomes available
- Algorithms process events in their own thread
- Multiple algorithms and events can be executed simultaneously
- Algorithm Cloning
  - Multiple instances of the same Algorithm can exist, and be executed concurrently, each for different event



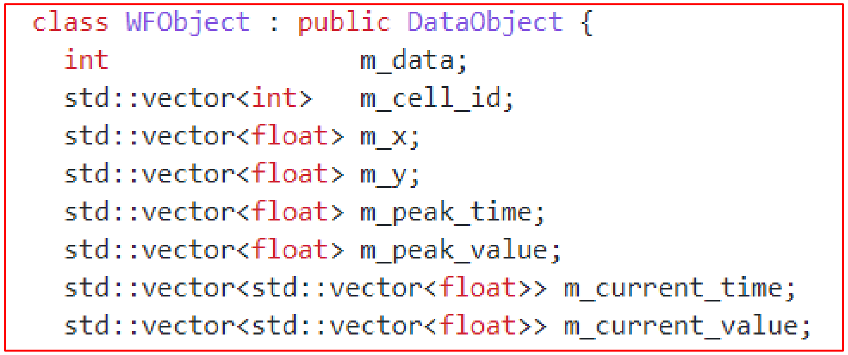
Example using dummy data object

- Performing the study using dummy data object





```
class EleObject : public DataObject {
  int                 m_data;
  std::vector<int>    m_cell_id;
  std::vector<float> m_x;
  std::vector<float> m_y;
```

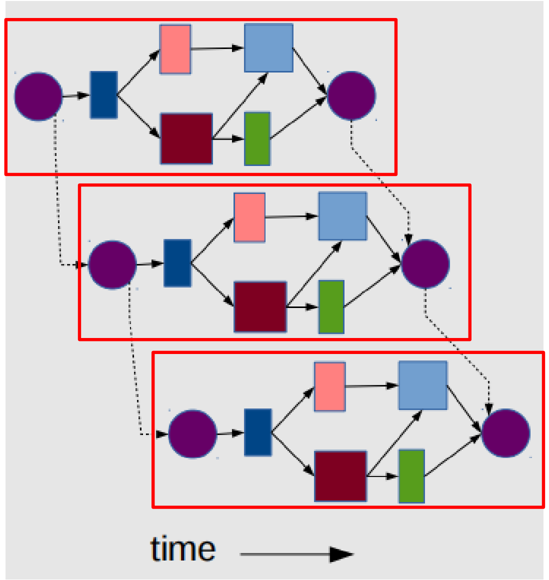


```
class WFObject : public DataObject {
  int                 m_data;
  std::vector<int>    m_cell_id;
  std::vector<float> m_x;
  std::vector<float> m_y;
  std::vector<float> m_peak_time;
  std::vector<float> m_peak_value;
  std::vector<std::vector<float>> m_current_time;
  std::vector<std::vector<float>> m_current_value;
```

- Working well

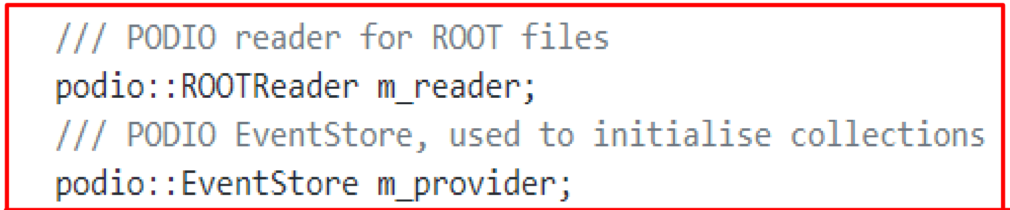
Example using dummy data object

- ❑ Some configurations:
  - ○ evtslots = 3 #number of events run in parallel
  - ○ whiteboard = HiveWhiteBoard("EventDataSvc", EventSlots=evtslots)
  - ○ scheduler = AvalancheSchedulerSvc(ThreadPoolSize=8)
  - ○ A1.Cardinality = 2 # number of instance of A1 after setting isClonable=true

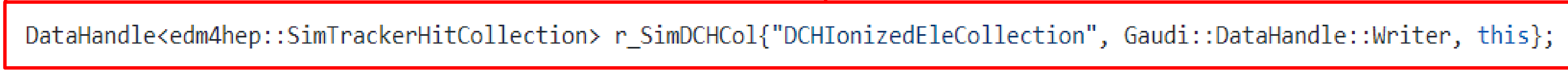


Example with podio input

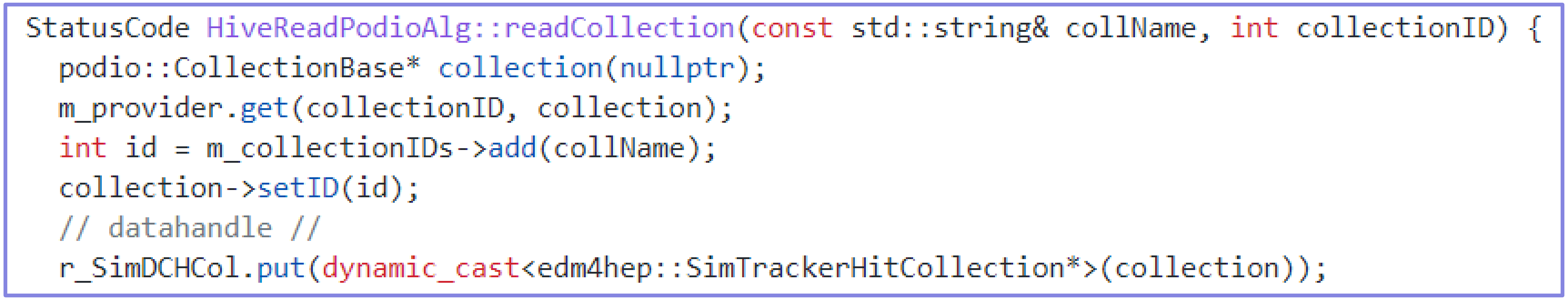
- Read podio data as input
- As the HiveWhiteBoard is used for event data service instead of PodioDataSvc. Currently, need create an algorithm to read podio data. People from key4hep is working on merging HiveWhiteBoard into PodioDataSvc



```
/// PODIO reader for ROOT files
podio::ROOTReader m_reader;
/// PODIO EventStore, used to initialise collections
podio::EventStore m_provider;
```



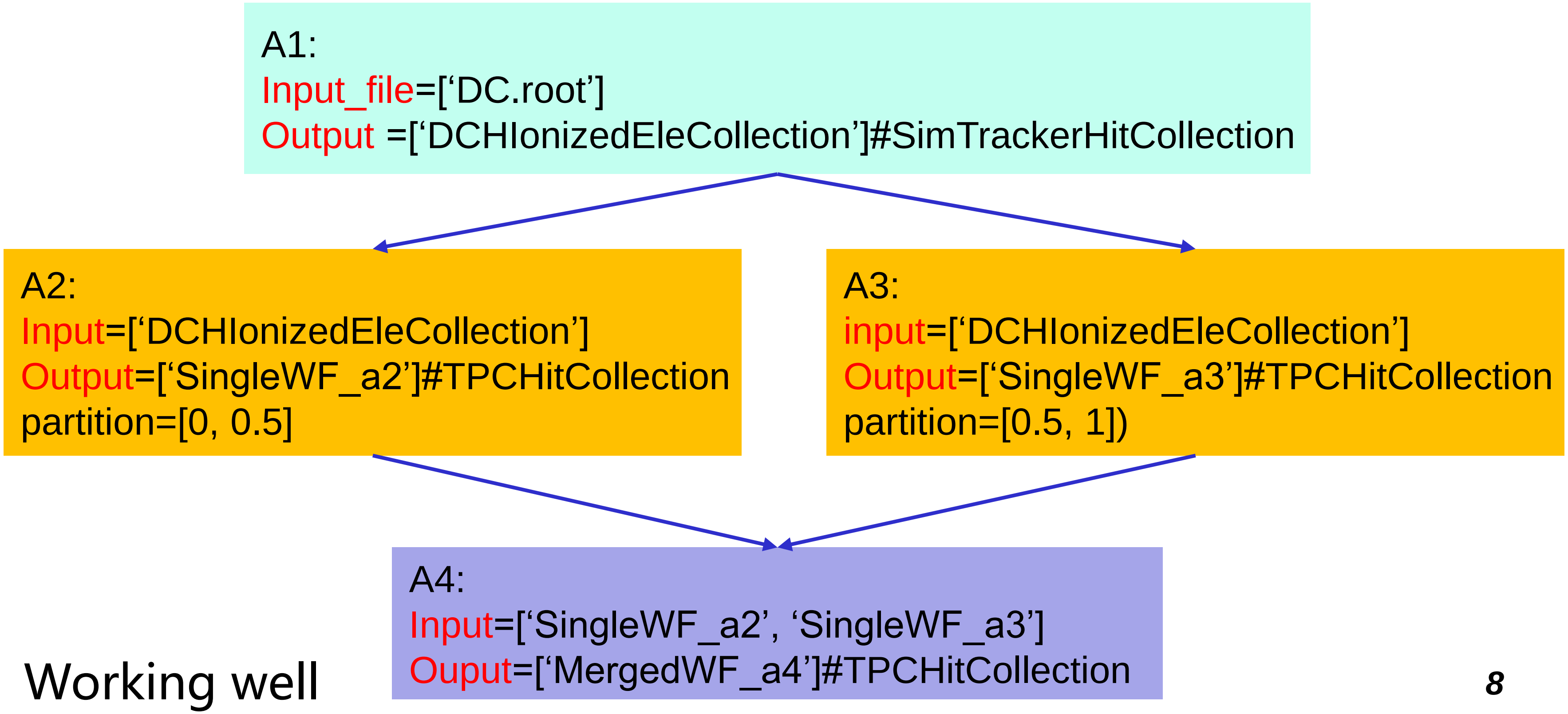
```
DataHandle<edm4hep::SimTrackerHitCollection> r_SimDCHCol{"DCHIonizedEleCollection", Gaudi::DataHandle::Writer, this};
```



```
StatusCode HiveReadPodioAlg::readCollection(const std::string& collName, int collectionID) {
  podio::CollectionBase* collection(nullptr);
  m_provider.get(collectionID, collection);
  int id = m_collectionIDs->add(collName);
  collection->setID(id);
  // datahandle //
  r_SimDCHCol.put(dynamic_cast<edm4hep::SimTrackerHitCollection*>(collection));
```

Example with podio input

- Read podio data as input and using edm4hep for EDM
- For this test, the edm4hep::SimTrackerHit is used for saving information of ionized electrons. The edm4hep::TPCHit is used for saving waveform information



```
A1:
Input_file=[‘DC.root’]
Output =[‘DCHIonizedEleCollection’]#SimTrackerHitCollection
```

```
A2:
Input=[‘DCHIonizedEleCollection’]
Output=[‘SingleWF_a2’]#TPCHitCollection
partition=[0, 0.5]
```

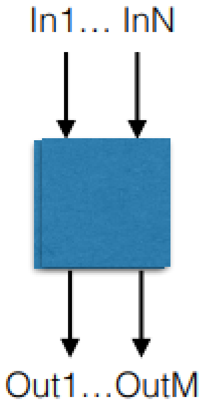
```
A3:
input=[‘DCHIonizedEleCollection’]
Output=[‘SingleWF_a3’]#TPCHitCollection
partition=[0.5, 1])
```

```
A4:
Input=[‘SingleWF_a2’, ‘SingleWF_a3’]
Ouput=[‘MergedWF_a4’]#TPCHitCollection
```

- Working well

Gaudi::Functional

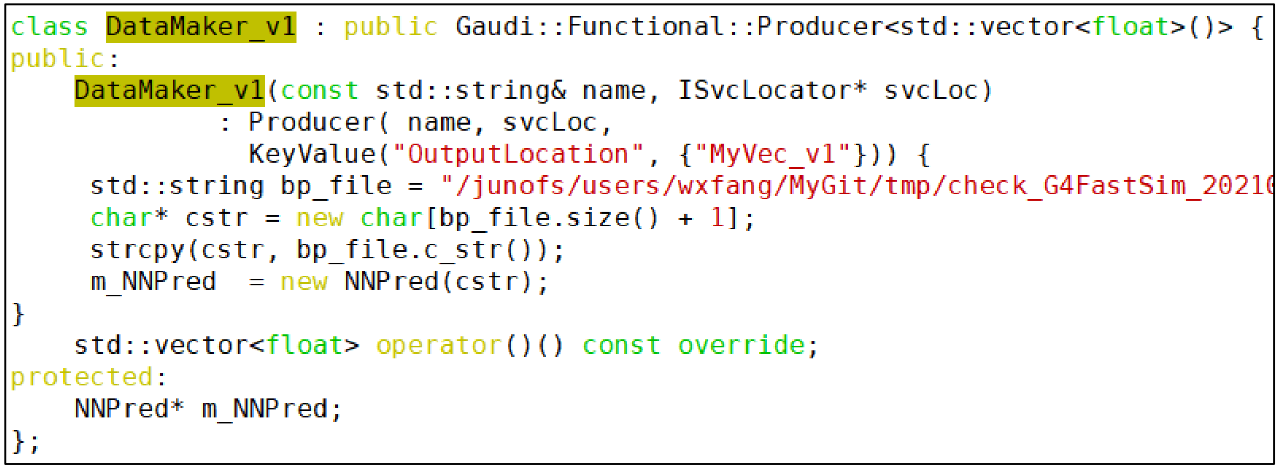
- Most algorithms look like "some data in" -> "some data out"
- Standardize the common pattern of getting data our of the TES, working on it, and putting it back in (in a different location).
  - Less code to write
  - More uniform code and easy to understand
  - Can be Re-Entrant, no need for clone, save memory
  - Multithreading friendly



- Patterns available:
  - Consumer, Producer, Filter, Transformer, MultiTransformer, ScalarTransformer, ...

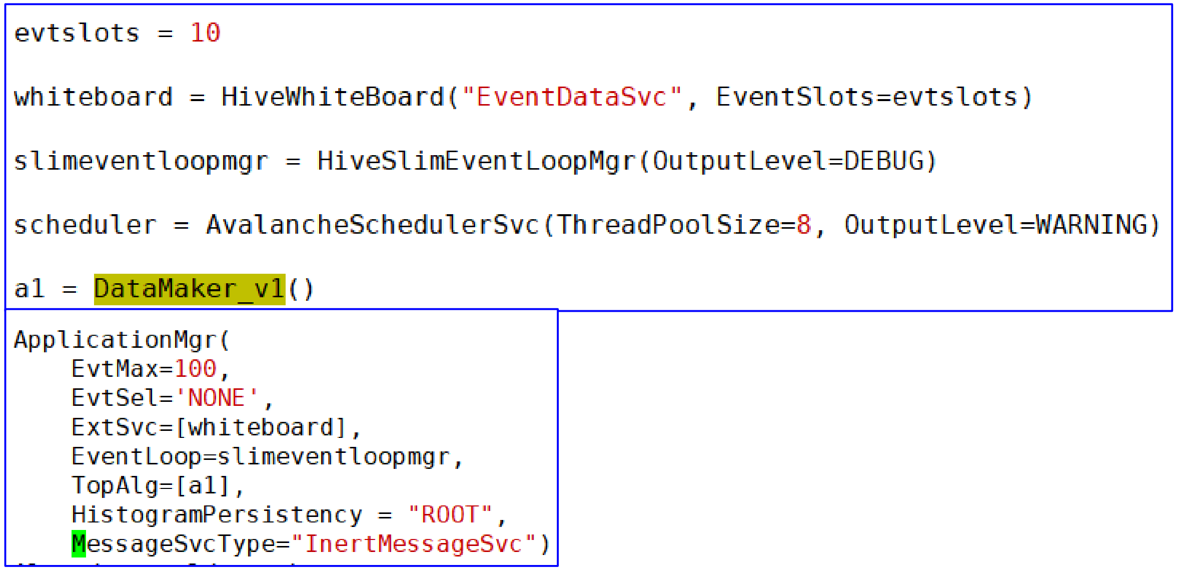
Re-Entrant test

- Gaudi::Functional Re-Entrant test

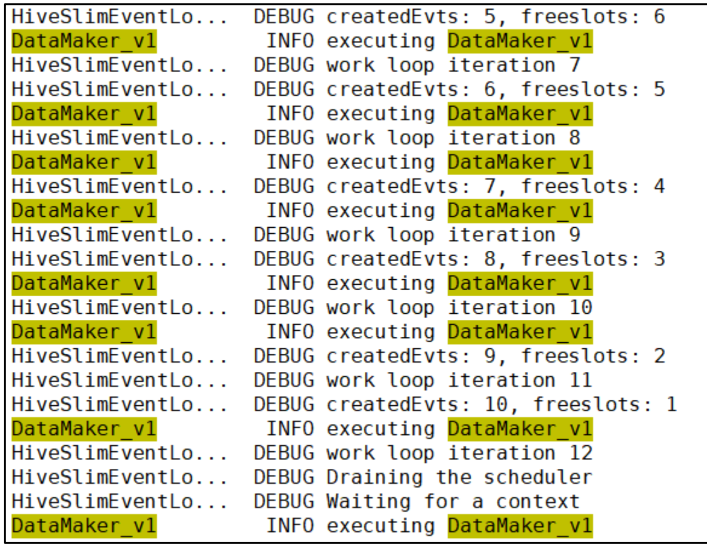


```cpp
class DataMaker_v1 : public Gaudi::Functional::Producer<std::vector<float>()> {
public:
    DataMaker_v1(const std::string& name, ISvcLocator* svcLoc)
             : Producer( name, svcLoc,
               KeyValue("OutputLocation", {"MyVec_v1"})) {
     std::string bp_file = "/junofs/users/wxfang/MyGit/tmp/check_G4FastSim_2021
     char* cstr = new char[bp_file.size() + 1];
     strcpy(cstr, bp_file.c_str());
     m_NNPred  = new NNPred(cstr);
}
    std::vector<float> operator()() const override;
protected:
    NNPred* m_NNPred;
};
```

- ❑ Gaudi::Functional is re-entrantable
- ❑ The pytorch model is re-entrantable

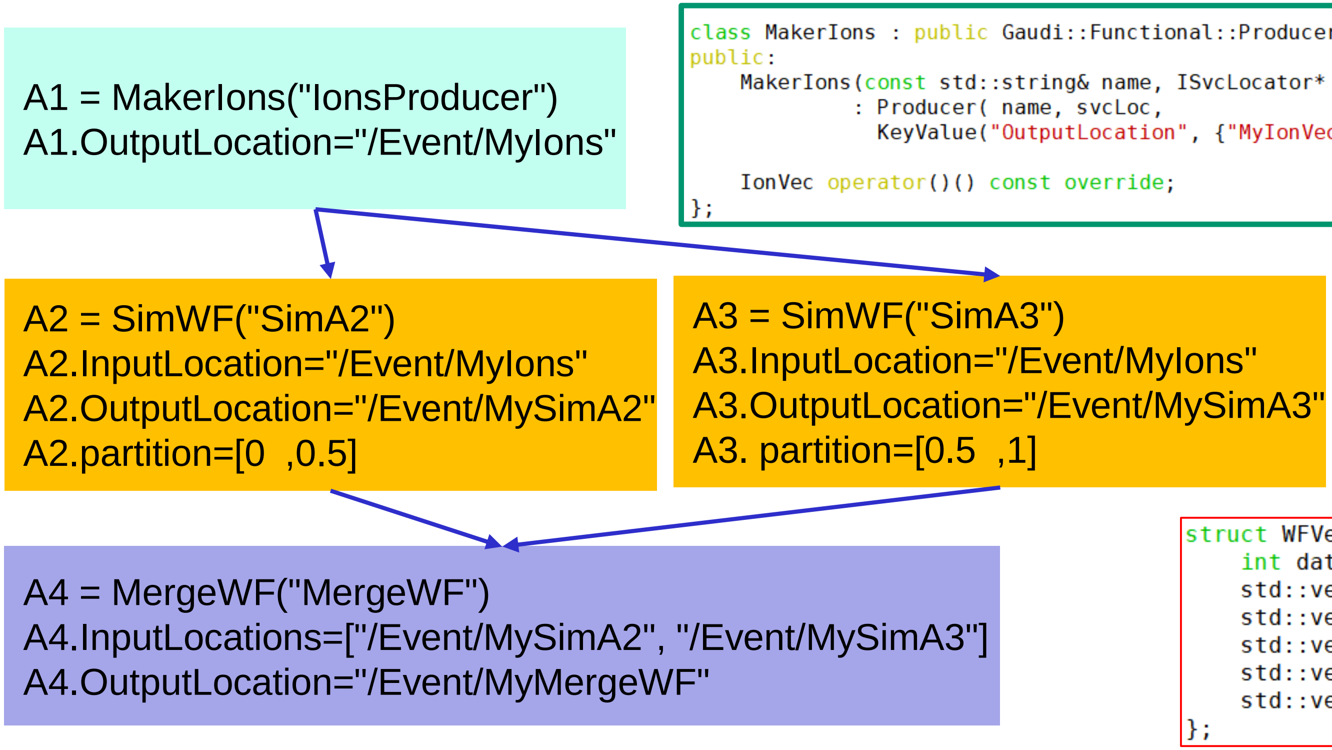


```python
evtslots = 10

whiteboard = HiveWhiteBoard("EventDataSvc", EventSlots=evtslots)

slimeventloopmgr = HiveSlimEventLoopMgr(OutputLevel=DEBUG)

scheduler = AvalancheSchedulerSvc(ThreadPoolSize=8, OutputLevel=WARNING)

a1 = DataMaker_v1()

ApplicationMgr(
    EvtMax=100,
    EvtSel='NONE',
    ExtSvc=[whiteboard],
    EventLoop=slimeventloopmgr,
    TopAlg=[a1],
    HistogramPersistency = "ROOT",
    MessageSvcType="InertMessageSvc")
```



```
HiveSlimEventLo...  DEBUG createdEvts: 5, freeslots: 6
DataMaker_v1         INFO executing DataMaker_v1
HiveSlimEventLo...  DEBUG work loop iteration 7
HiveSlimEventLo...  DEBUG createdEvts: 6, freeslots: 5
DataMaker_v1         INFO executing DataMaker_v1
HiveSlimEventLo...  DEBUG work loop iteration 8
DataMaker_v1         INFO executing DataMaker_v1
HiveSlimEventLo...  DEBUG createdEvts: 7, freeslots: 4
DataMaker_v1         INFO executing DataMaker_v1
HiveSlimEventLo...  DEBUG work loop iteration 9
HiveSlimEventLo...  DEBUG createdEvts: 8, freeslots: 3
DataMaker_v1         INFO executing DataMaker_v1
HiveSlimEventLo...  DEBUG work loop iteration 10
DataMaker_v1         INFO executing DataMaker_v1
HiveSlimEventLo...  DEBUG createdEvts: 9, freeslots: 2
HiveSlimEventLo...  DEBUG work loop iteration 11
HiveSlimEventLo...  DEBUG createdEvts: 10, freeslots: 1
DataMaker_v1         INFO executing DataMaker_v1
HiveSlimEventLo...  DEBUG work loop iteration 12
HiveSlimEventLo...  DEBUG Draining the scheduler
HiveSlimEventLo...  DEBUG Waiting for a context
DataMaker_v1         INFO executing DataMaker_v1
```

Using Gaudi::Functional



A1 = MakerIons("IonsProducer")
A1.OutputLocation="/Event/MyIons"

A2 = SimWF("SimA2")
A2.InputLocation="/Event/MyIons"
A2.OutputLocation="/Event/MySimA2"
A2.partition=[0 ,0.5]

A3 = SimWF("SimA3")
A3.InputLocation="/Event/MyIons"
A3.OutputLocation="/Event/MySimA3"
A3. partition=[0.5 ,1]

A4 = MergeWF("MergeWF")
A4.InputLocations=["/Event/MySimA2", "/Event/MySimA3"]
A4.OutputLocation="/Event/MyMergeWF"

```
class MakerIons : public Gaudi::Functional::Producer<IonVec()> {
public:
    MakerIons(const std::string& name, ISvcLocator* svcLoc)
             : Producer( name, svcLoc,
               KeyValue("OutputLocation", {"MyIonVec"})) {}

    IonVec operator()() const override;
};
```

```
struct IonVec{
    int data;
    std::vector<int> cell_id;
    std::vector<float> x;
    std::vector<float> y;
};
```

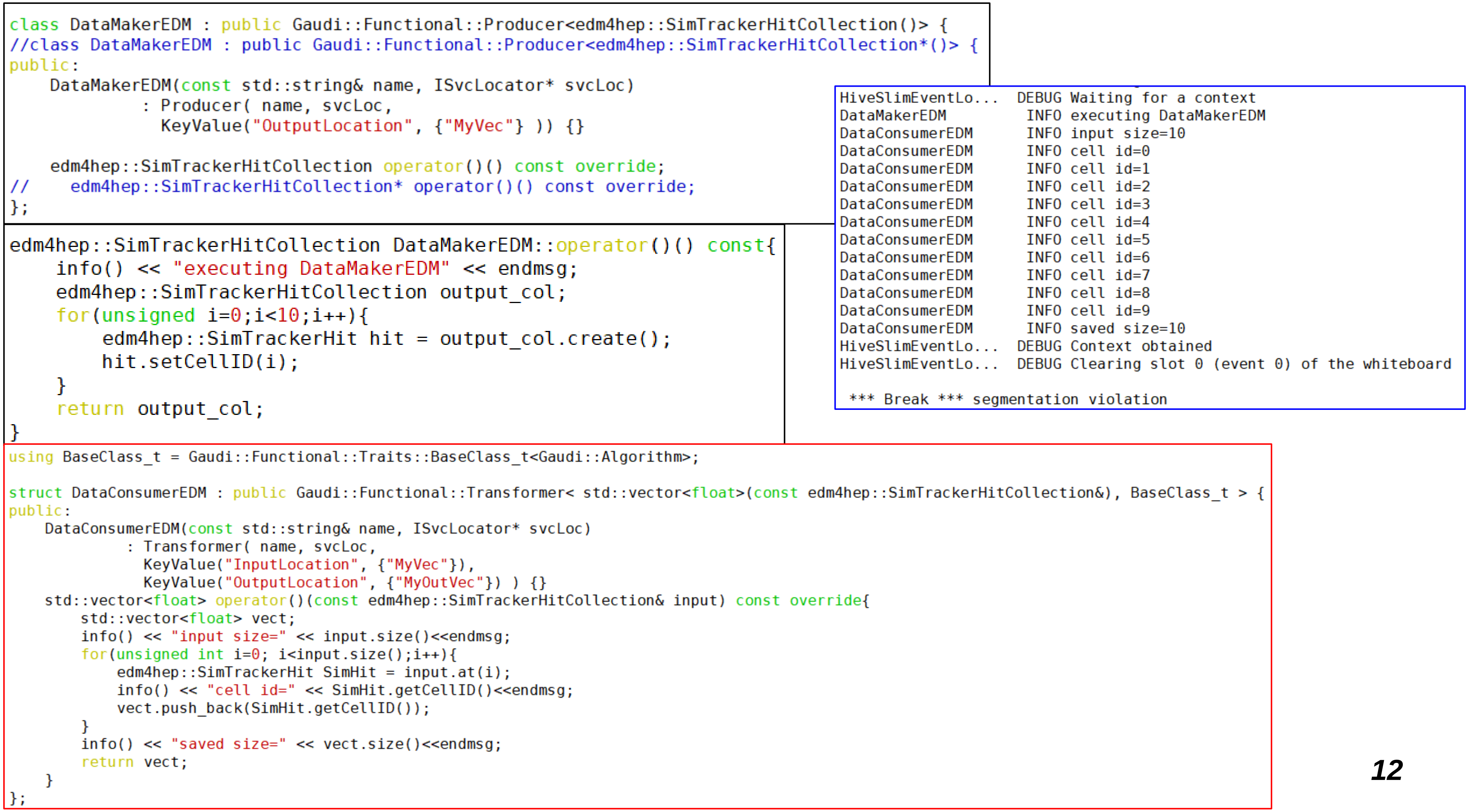
```
struct WFVec{
    int data;
    std::vector<int> e_id;
    std::vector<int> cell_id;
    std::vector<float> peak_time;
    std::vector<float> peak_value;
    std::vector<std::vector<float> > charges;
};
```

```
using BaseClass_t = Gaudi::Functional::Traits::BaseClass_t<Gaudi::Algorithm>;
struct SimWF final : Gaudi::Functional::Transformer<WFVec( const IonVec& ), BaseClass_t> {

  SimWF( const std::string& name, ISvcLocator* svcLoc )
      : Transformer( name, svcLoc, KeyValue( "InputLocation", "/Event/MyInt" ),
                     KeyValue( "OutputLocation", "/Event/MyFloat" ) ) {}
  WFVec operator()( const IonVec& input ) const override {
```

```
struct MergeWF final : Gaudi::Functional::MergingTransformer<WFVec( const Gaudi::Functional::vector_of_const_<WFVec>& ), BaseClass_t> {

  MergeWF( const std::string& name, ISvcLocator* svcLoc )
      : MergingTransformer( name, svcLoc, {"InputLocations", {}},{"OutputLocation", "/Event/MyConcatenatedIntVector"} ) {}

  WFVec operator()( const Gaudi::Functional::vector_of_const_<WFVec>& input ) const override {
```

Using Gaudi::Functional

❖ Using edm4hep data. Data can be accessed correctly. However, at the end of event, error happens



```
class DataMakerEDM : public Gaudi::Functional::Producer<edm4hep::SimTrackerHitCollection()> {
//class DataMakerEDM : public Gaudi::Functional::Producer<edm4hep::SimTrackerHitCollection*()> {
public:
    DataMakerEDM(const std::string& name, ISvcLocator* svcLoc)
             : Producer( name, svcLoc,
               KeyValue("OutputLocation", {"MyVec"} )) {}

    edm4hep::SimTrackerHitCollection operator()() const override;
//    edm4hep::SimTrackerHitCollection* operator()() const override;
};
```

```
edm4hep::SimTrackerHitCollection DataMakerEDM::operator()() const{
    info() << "executing DataMakerEDM" << endmsg;
    edm4hep::SimTrackerHitCollection output_col;
    for(unsigned i=0;i<10;i++){
        edm4hep::SimTrackerHit hit = output_col.create();
        hit.setCellID(i);
    }
    return output_col;
}
```

```
HiveSlimEventLo...  DEBUG Waiting for a context
DataMakerEDM         INFO executing DataMakerEDM
DataConsumerEDM      INFO input size=10
DataConsumerEDM      INFO cell id=0
DataConsumerEDM      INFO cell id=1
DataConsumerEDM      INFO cell id=2
DataConsumerEDM      INFO cell id=3
DataConsumerEDM      INFO cell id=4
DataConsumerEDM      INFO cell id=5
DataConsumerEDM      INFO cell id=6
DataConsumerEDM      INFO cell id=7
DataConsumerEDM      INFO cell id=8
DataConsumerEDM      INFO cell id=9
DataConsumerEDM      INFO saved size=10
HiveSlimEventLo...  DEBUG Context obtained
HiveSlimEventLo...  DEBUG Clearing slot 0 (event 0) of the whiteboard

 *** Break *** segmentation violation
```

```
using BaseClass_t = Gaudi::Functional::Traits::BaseClass_t<Gaudi::Algorithm>;

struct DataConsumerEDM : public Gaudi::Functional::Transformer< std::vector<float>(const edm4hep::SimTrackerHitCollection&), BaseClass_t > {
public:
    DataConsumerEDM(const std::string& name, ISvcLocator* svcLoc)
             : Transformer( name, svcLoc,
               KeyValue("InputLocation", {"MyVec"}),
               KeyValue("OutputLocation", {"MyOutVec"}) ) {}
    std::vector<float> operator()(const edm4hep::SimTrackerHitCollection& input) const override{
        std::vector<float> vect;
        info() << "input size=" << input.size()<<endmsg;
        for(unsigned int i=0; i<input.size();i++){
            edm4hep::SimTrackerHit SimHit = input.at(i);
            info() << "cell id=" << SimHit.getCellID()<<endmsg;
            vect.push_back(SimHit.getCellID());
        }
        info() << "saved size=" << vect.size()<<endmsg;
        return vect;
    }
};
```

Summary

- The Gaudi Hive is studied for multithreaded simulation of drift chamber
- User defined or edm4hep format data is supported in Gaudi Hive
- Using Gaudi::Functional instead of Algorithm have been tried, finding problems with edm4hep data, under investigation

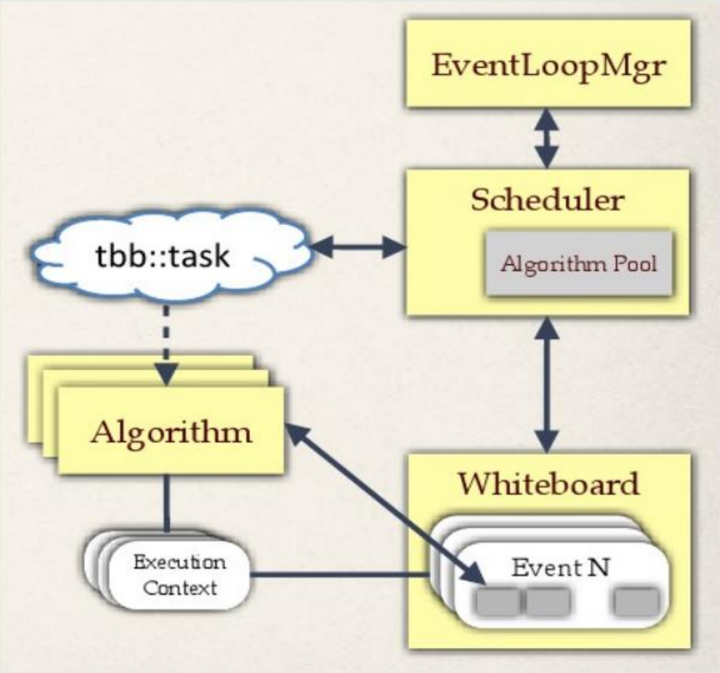
- Future plan:
  - Try to write the output to root files
  - Combining with Geant4 simulation
  - Integrating with k4FWCore, maybe develop a multithreading version of k4FWCore
  - Creating a prototype of CEPCSW based on GaudiHive
- Welcome to check the code: https://github.com/wenxingfang/DCMTSim

Back up

Gaudi Hive Operation

Charles Leggett
September 18 2015

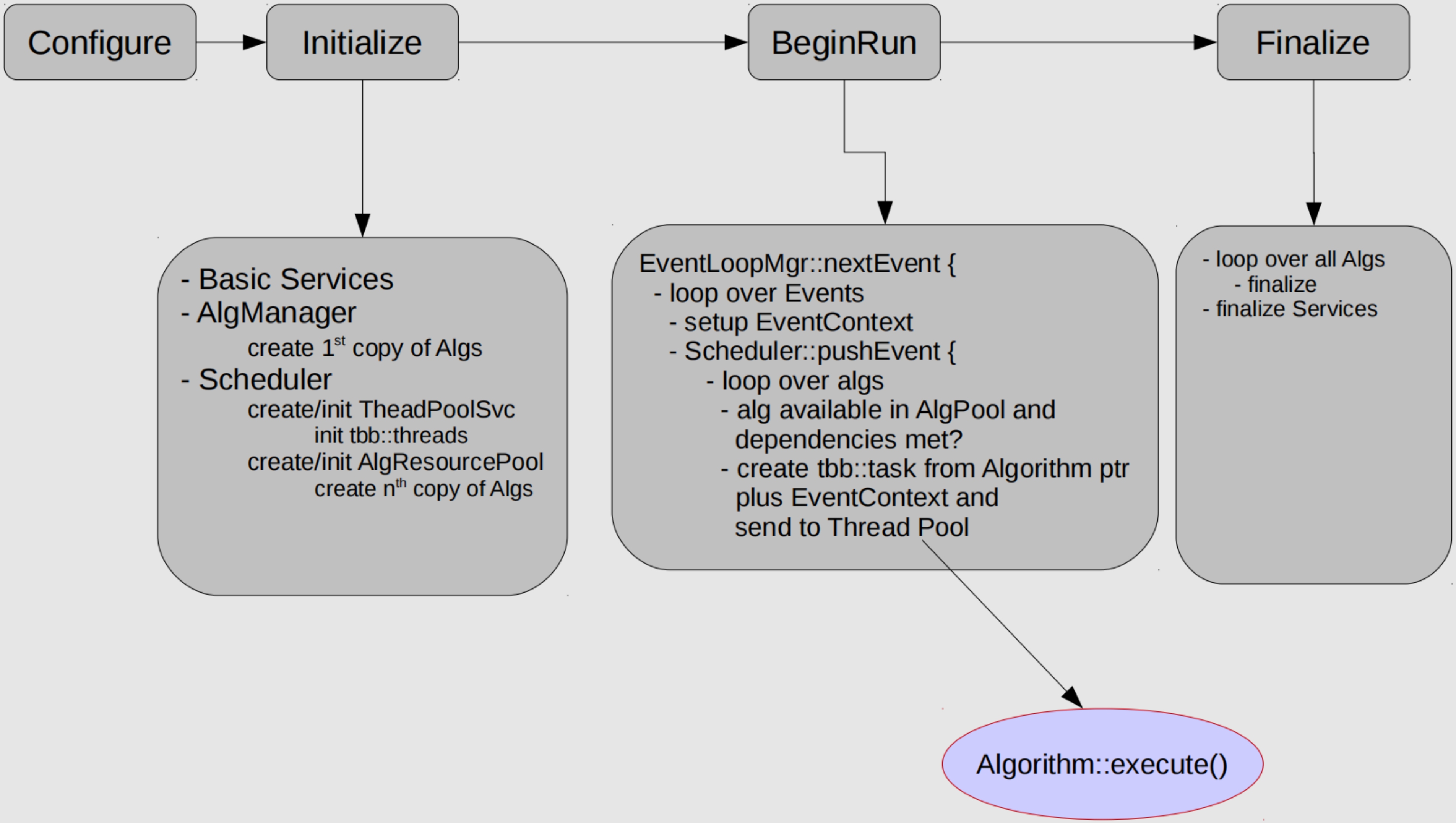
- Configuration, Initialization, Finalization are performed serially in "master" thread
  - only Algorithm::execute is concurrent
- Algorithms are scheduled when data becomes available
  - Algorithms must declare their inputs at initialization or dynamically with DataHandles
  - tbb::task wraps the pair (Algorithm*, EventContext)
- Several instances of the same Algorithm can co-exist
  - **cloning**: create new instance if can be scheduled, and all other instances busy
  - running on different events
  - managed by AlgoPool



- Multiple events are managed simultaneously
  - increases probability of scheduling an Algorithm
  - whiteboard DataStore is thread safe

Execution Flow

Charles Leggett
September 18 2015



Configure

Initialize

BeginRun

Finalize

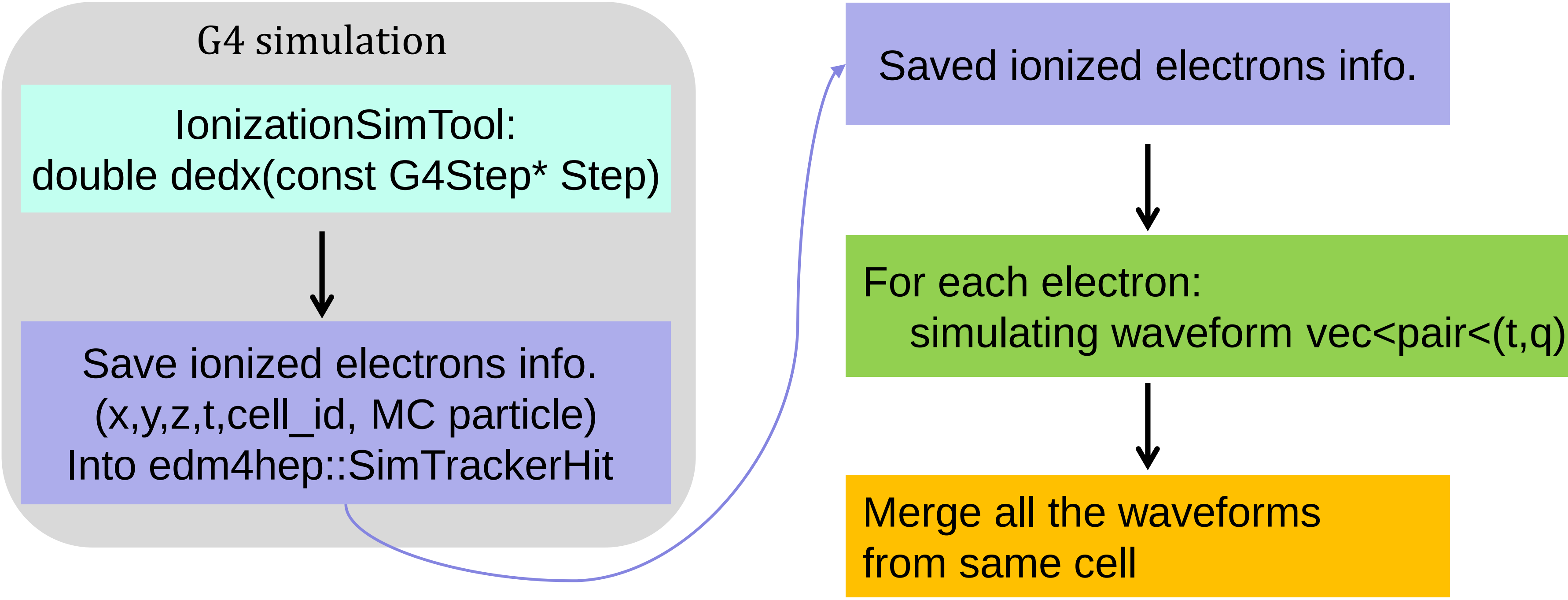
- Basic Services
- AlgManager
    create 1st copy of Algs
- Scheduler
    create/init TheadPoolSvc
        init tbb::threads
    create/init AlgResourcePool
        create nth copy of Algs

```
EventLoopMgr::nextEvent {
  - loop over Events
    - setup EventContext
    - Scheduler::pushEvent {
        - loop over algs
          - alg available in AlgPool and
            dependencies met?
          - create tbb::task from Algorithm ptr
            plus EventContext and
            send to Thread Pool
```

- loop over all Algs
    - finalize
- finalize Services

Algorithm::execute()

Ionization and waveform simulation



G4 simulation

IonizationSimTool:
double dedx(const G4Step* Step)

Save ionized electrons info.
(x,y,z,t,cell_id, MC particle)
Into edm4hep::SimTrackerHit

Saved ionized electrons info.

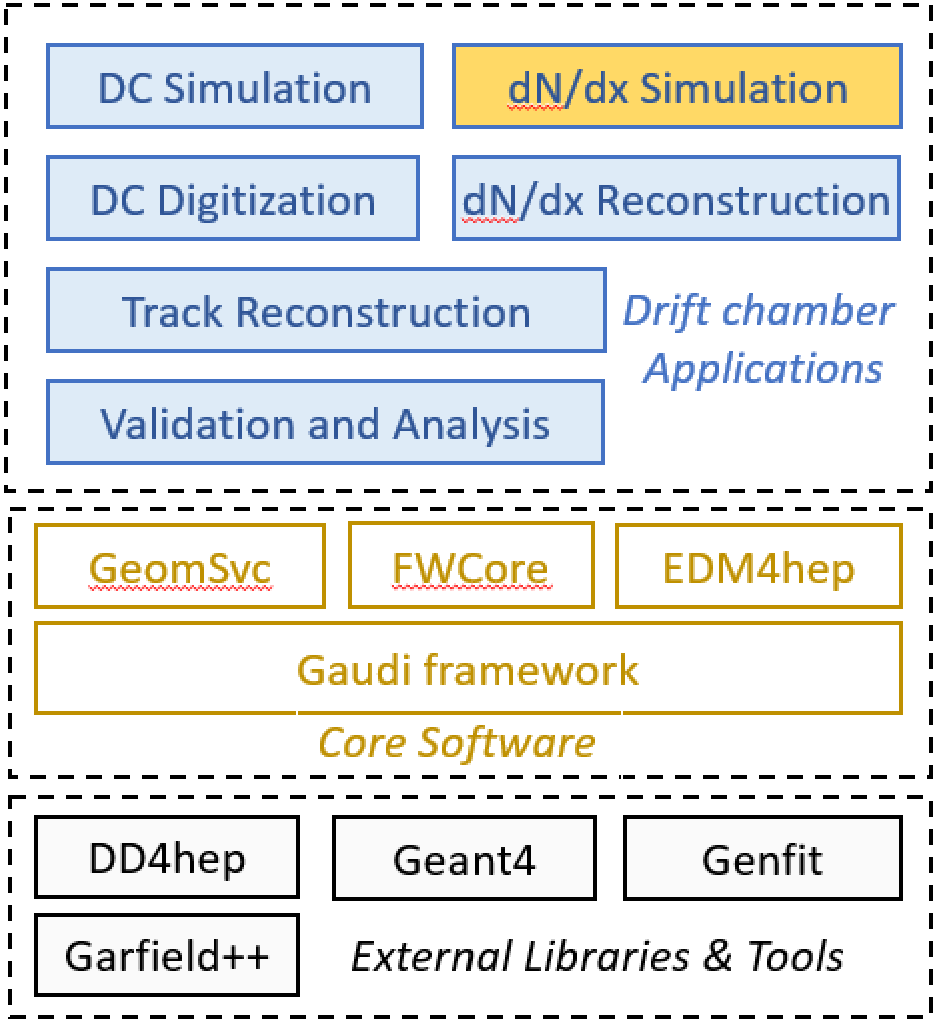
For each electron:
simulating waveform vec<pair<(t,q)

Merge all the waveforms
from same cell

- ❖ Most time consuming part:
  - ➢ Simulate waveform for each electron
  - ➢ For one cell, ~ 100 electrons:
    - o Using Garfield++: ~250 s
    - o Using ML fast simulation: ~1 s
- ❖ CEPC drift chamber is ~100 layers, for one track ~ 100 s. Need further speed up. Using multithreading or GPU technique.

CEPCSW for drift chamber

- Framework:
  - Gaudi
- EDM:
  - EDM4hep
  - FWCore
- Detector geometry and B field:
  - DD4hep
  - GeomSvc
- Drift chamber:
  - DC simulation (Geant4)
  - DC digitization
  - Track reconstruction (Genfit)
  - dN/dx simulation (Garfield++)
  - dN/dx reconstruction



https://github.com/cepc/CEPCSW