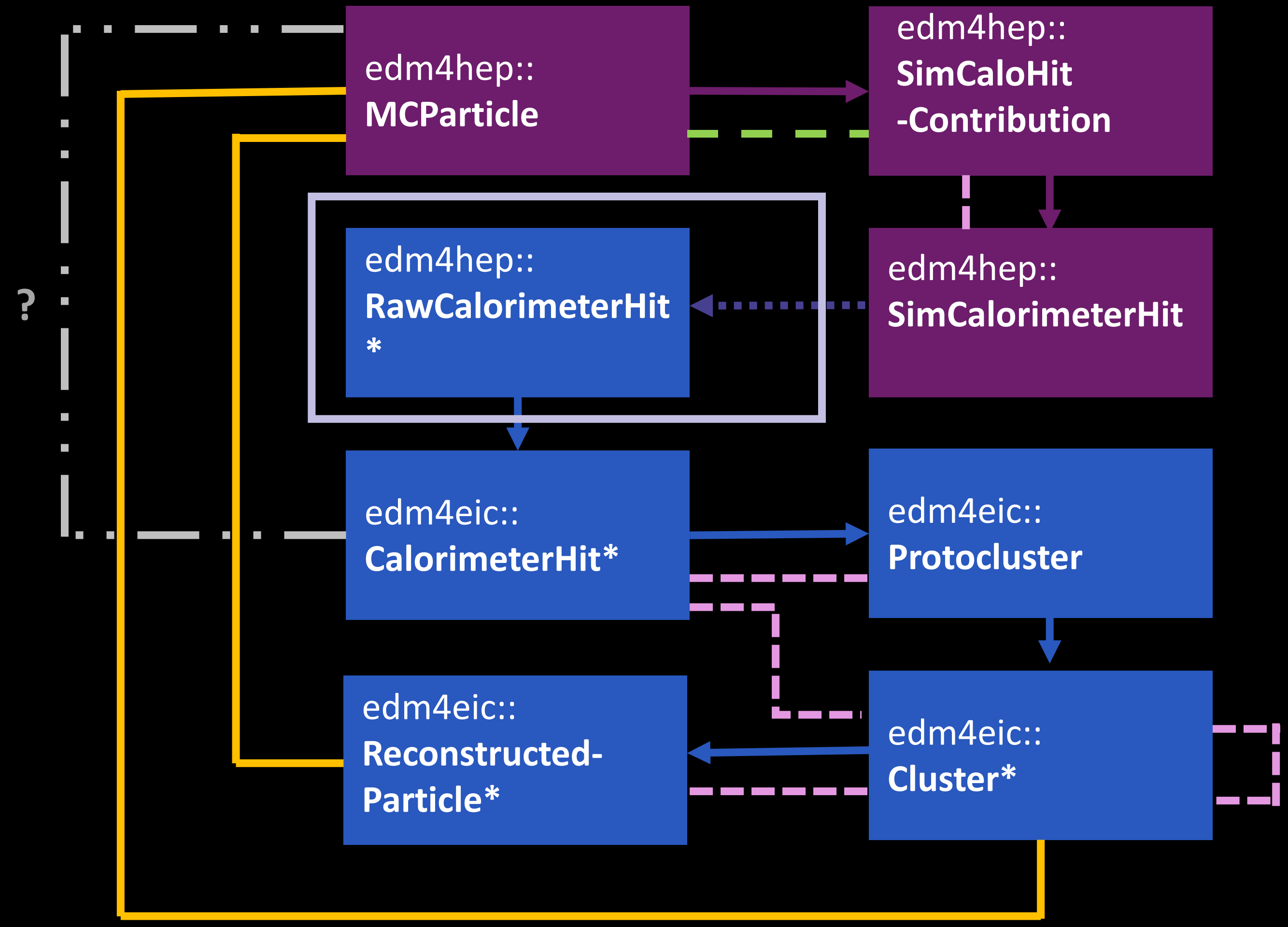
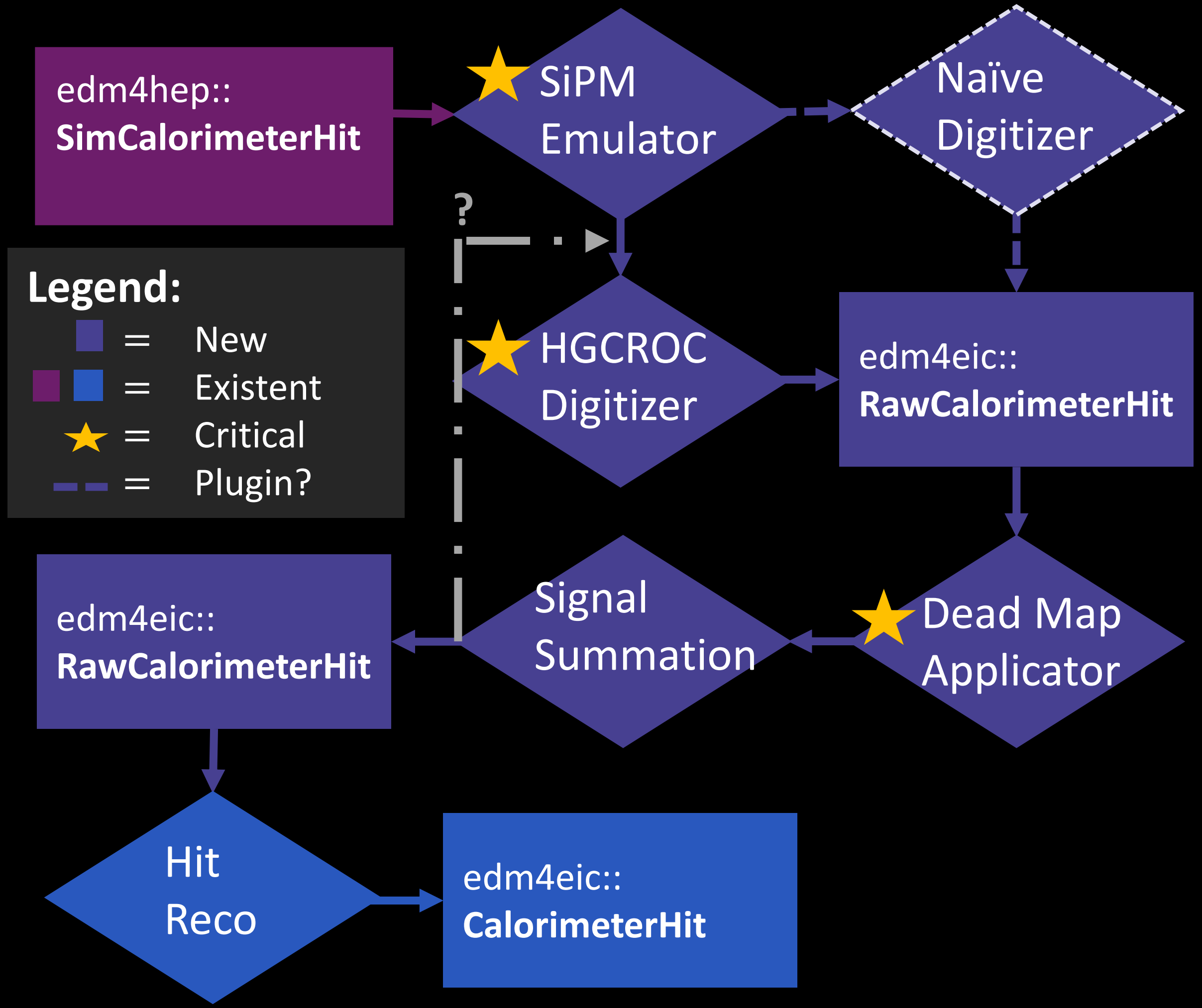
HGCROC Emulation Notes | where would it go?



- **While at ORNL:** discussed how we might extend our current digitization routine to better emulate actual HGCROC
  - In particular, 2 major pieces currently missing:
    - a) Ability to apply dead maps and turn off specific channels
    - b) Ability to robustly inject noise during digitization
  - Both will be critical for LFHCAL (and others) TDR studies

- **Light purple box:** where we would add nodes to the algorithmic flow to enable these

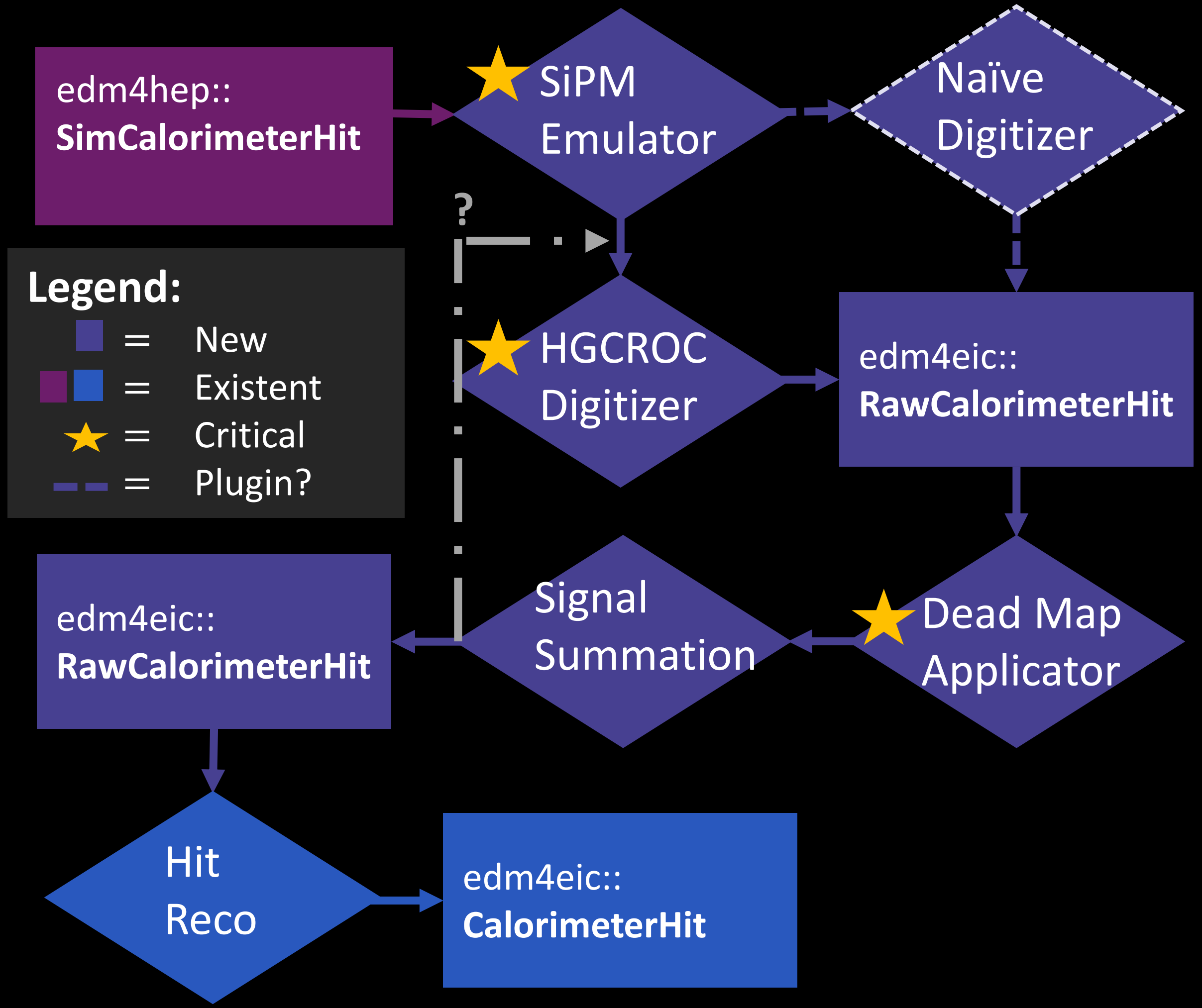
HGCROC Emulation Notes | strawman algorithm flow



SiPM Emulator

- Note that Dima started work towards this in PR #1064
- Generates waveform from input simulated "hit"
  - ☞ (i.e. total deposited energy in a cell)
- Noise would be injected here
  - › Could implement such that:
    - + Provide a map/matrix of where to apply noise
    - + Some functional form of the noise to apply
- Need option to turn off individual channels here
  - ☞ (For calo.s which gang together signals downstream)

HGCROC Emulation Notes | strawman algorithm flow



Naïve Digitizer

– Integrates over waveform with some specified precision

– Useful for benchmarking/debugging

  ☞ Could potentially be implemented as a benchmark/plugin

HGCROC Digitizer

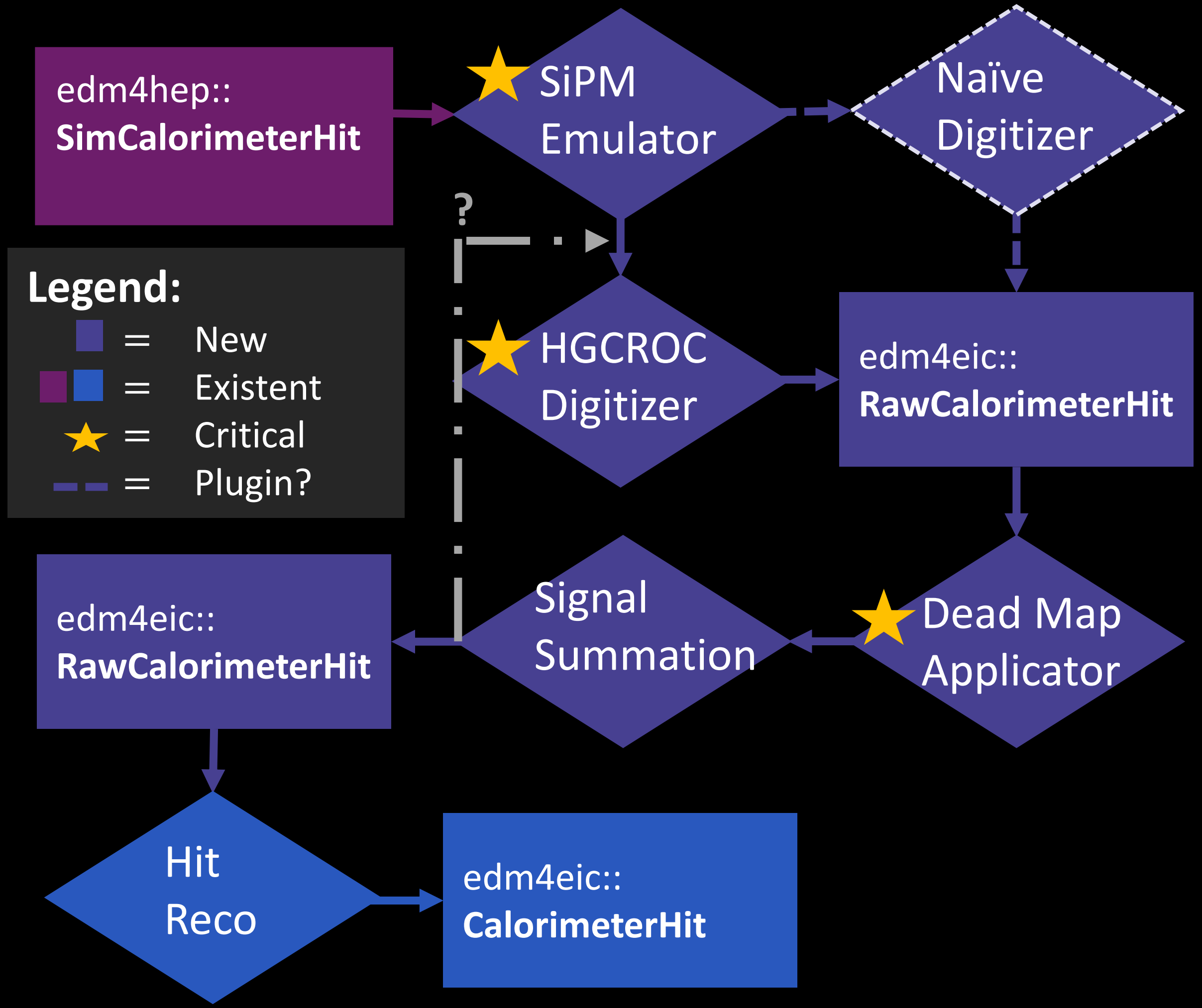
– Needs option to sum signals before digitizing

  › Could be a separate algorithm

– At minimum, would get maximum from SiPM signal

  › Can be expanded later to include ToT and ToA info

HGCROC Emulation Notes | strawman algorithm flow



Dead Map Applicator

- Could be implemented similar to noise injection in the SiPM emulator
  - i.e. a map/matrix is provided which indicates which channel are to be killed

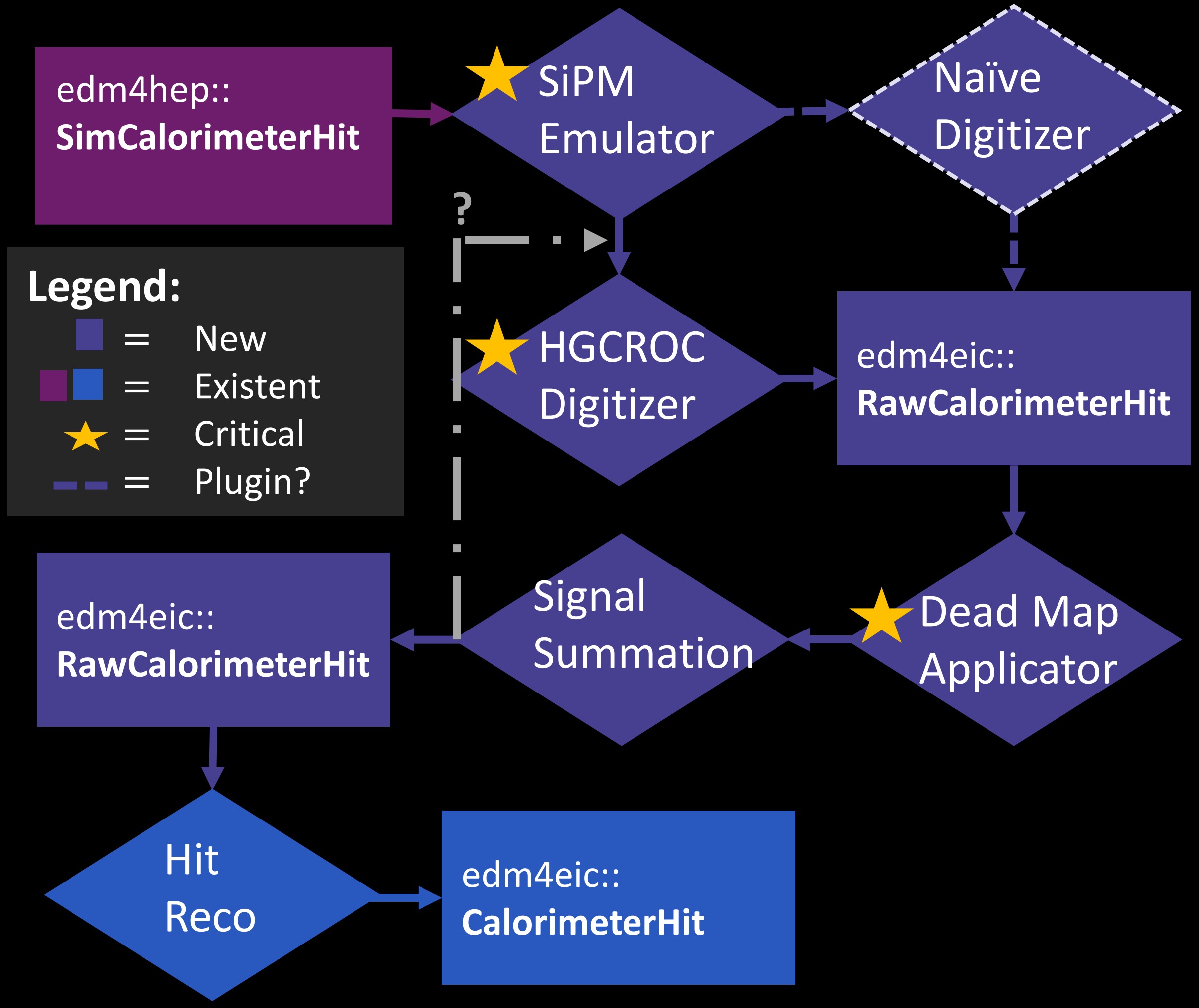
Signal Summation

- Here is where the LFHCAL would gang together channels into superchannels
  - Possibly likewise for the BIC
- For LFHCAL, should go before digitizer

Hit Reconstruction

- May need new reconstruction algorithm to combine ToT, ToA, and ADC
- **Note:** summation currently handled here

HGCROC Emulation Notes | strawman algorithm flow



edm4hep::
SimCalorimeterHit

★ SiPM Emulator

Naïve Digitizer

?

★ HGCROC Digitizer

edm4eic::
RawCalorimeterHit

Signal Summation

★ Dead Map Applicator

edm4eic::
RawCalorimeterHit

Hit Reco

edm4eic::
CalorimeterHit

Legend:

🟪 = New

🟪🟦 = Existent

★ = Critical

– – = Plugin?

Notes on Data Types

- May need new types in data model to implement this properly
  - › e.g. an `HGCROCRawHit` which has ADC, ToT, and ToA
  - › Or a `SiPMSignal` which encodes the waveformm

Food for Thought

- Are there additional checks to build in to make sure the right collections are being fed into the right factories?
  - › Possibly add a `char_t` to index which detector the hit belongs to?
  - › Might be tricky to generalize, though…

Previous C/S Meeting Slides

02.21.2024

Calo Data Model Discussion

- **Right:** summary of identified data model and reconstruction needs/wants from January CM
  - c.f. this summary of the CM discussion for more details
- **Since then:** there has been some discussion, but so far no additional *data model* needs have been identified
  - e.g. BEMC team identified need for including attenuated hits from right/left side of BEMC for threshold studies

Identified Data Model Needs

- Improved truth-Cluster connections

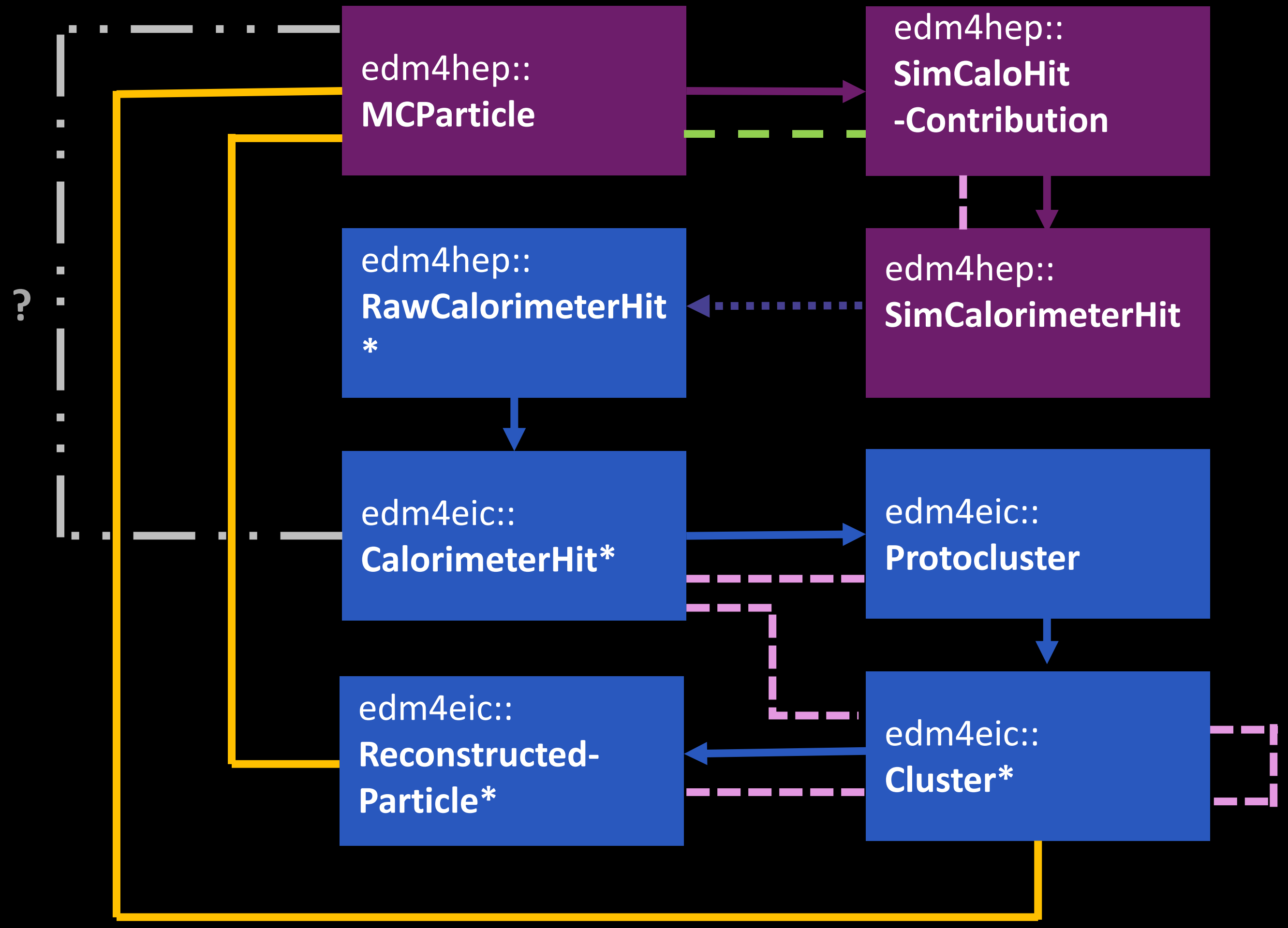
Identified Reconstruction Needs/Wants

- Clustering implemented in all systems
- Cluster splitting/merging
- ML Integration
- Digitization noise, noise-masking and system-specific digitization model implementations
- Better neutral identification
- Easier access to janadot output

Identified Simulation Needs/Wants

- Enhanced realism in BEMC implementation and implementation of end-of-sector box material
- Dedicated studies of HGCROC vs. waveform digitizer in BEMC
- Physics-driven performance studies for nHCal
- Update ZDC default to SiPM-on-tile
- Enhanced realism in pECal implementation

Calo Data Model Discussion | Overview



?

edm4hep:: **MCParticle**

edm4hep:: **SimCaloHit -Contribution**

edm4hep:: **RawCalorimeterHit ***

edm4hep:: **SimCalorimeterHit**

edm4eic:: **CalorimeterHit***

edm4eic:: **Protocluster**

edm4eic:: **Reconstructed- Particle***

edm4eic:: **Cluster***

Legend:

◀┈ = Digitization

━ = Assocation

╍ = One-to-one relation

┅ = One-to-many relation

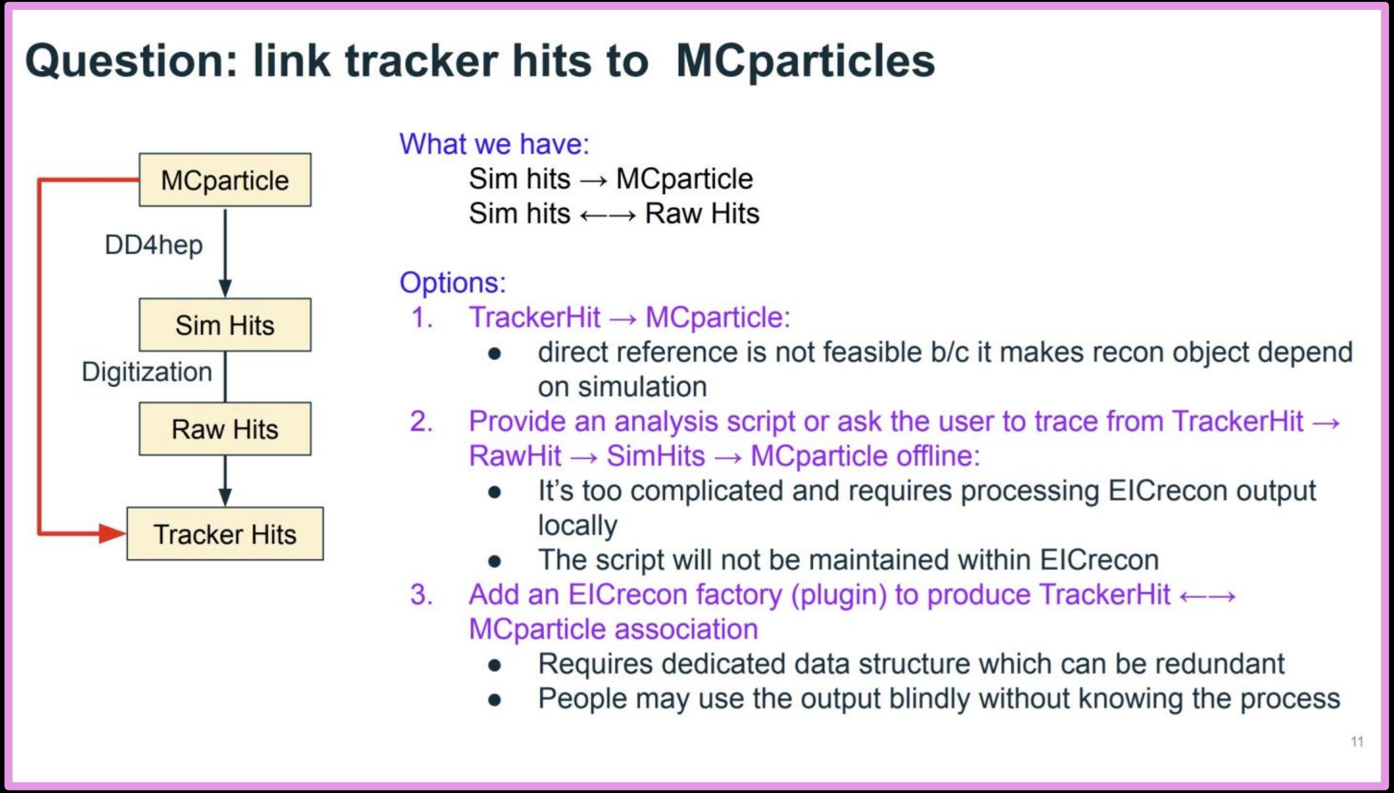
■ = DD4hep

■ = EICrecon

* Saved to EICrecon output by default

Calo Data Model Discussion | Previous Discussion

- **Right:** Slide from Shujie & Joe for C/S meeting on February 7th
  - Calo situation very much parallels the TrackerHit → MCParticle discussion
  - As far as I can tell: discussion hasn't converged yet…



Question: link tracker hits to MCparticles

What we have:

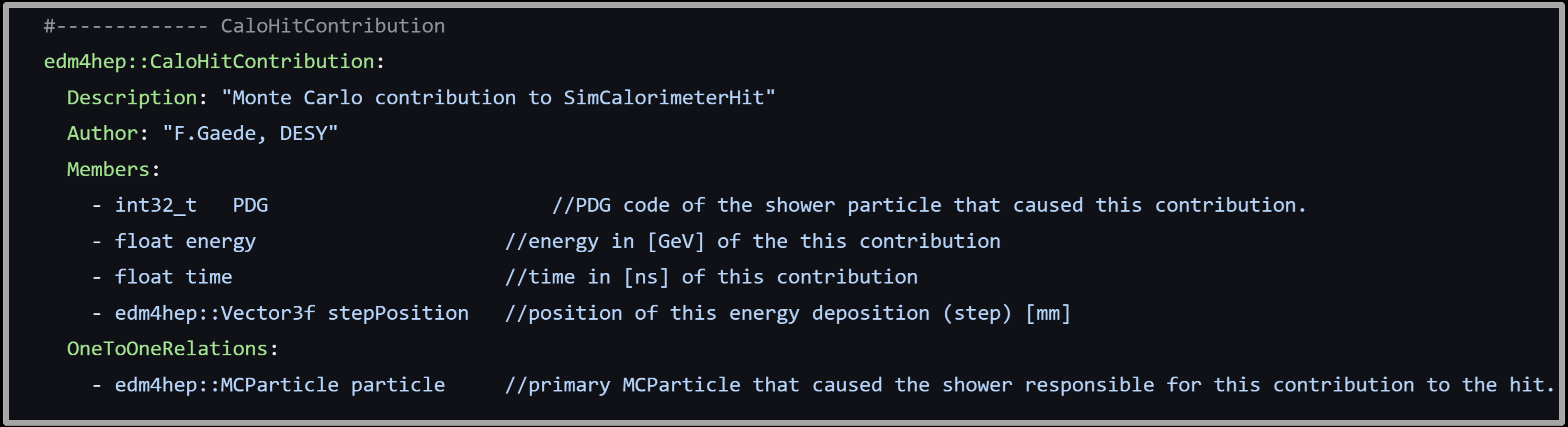
Sim hits → MCparticle
Sim hits ←→ Raw Hits

Options:

1. TrackerHit → MCparticle:
   - direct reference is not feasible b/c it makes recon object depend on simulation
2. Provide an analysis script or ask the user to trace from TrackerHit → RawHit → SimHits → MCparticle offline:
   - It's too complicated and requires processing EICrecon output locally
   - The script will not be maintained within EICrecon
3. Add an EICrecon factory (plugin) to produce TrackerHit ←→ MCparticle association
   - Requires dedicated data structure which can be redundant
   - People may use the output blindly without knowing the process

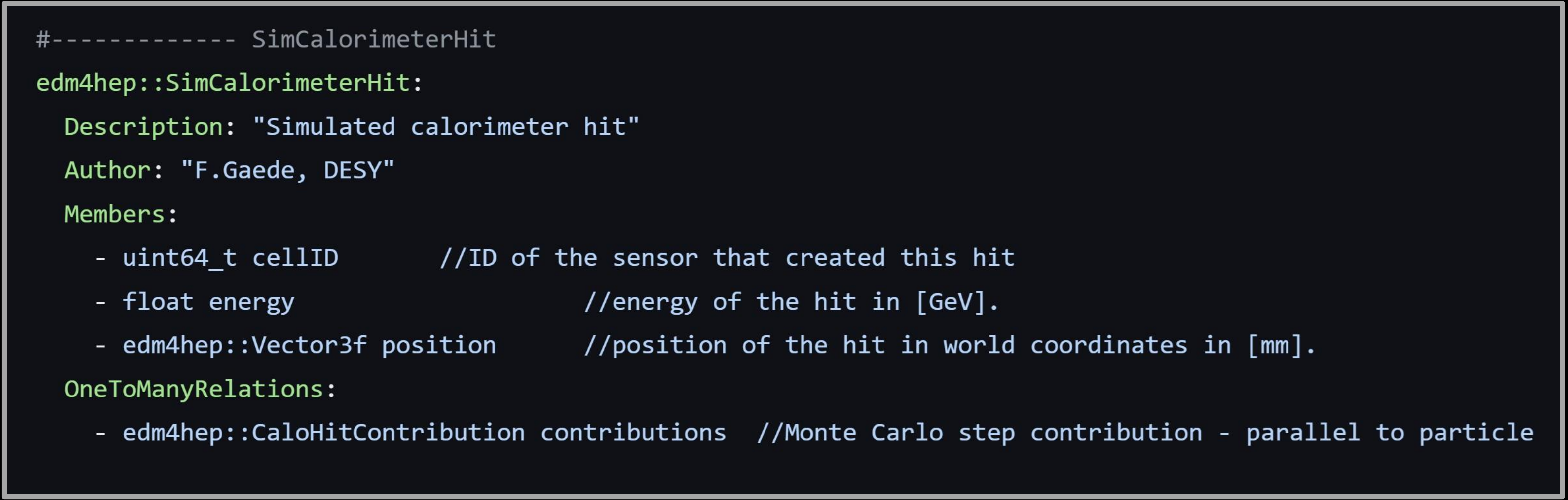
11

Backup | edm4hep::SimCaloHitContribution



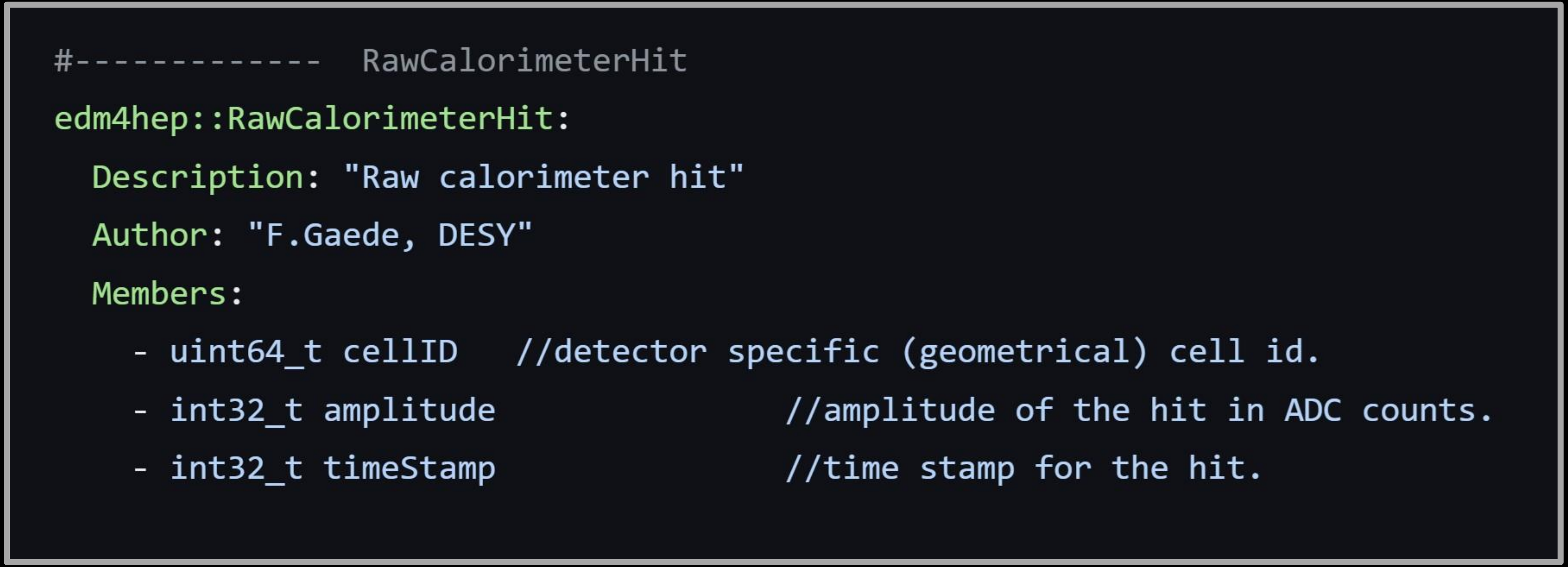
```
#------------- CaloHitContribution
edm4hep::CaloHitContribution:
  Description: "Monte Carlo contribution to SimCalorimeterHit"
  Author: "F.Gaede, DESY"
  Members:
    - int32_t   PDG                        //PDG code of the shower particle that caused this contribution.
    - float energy                     //energy in [GeV] of the this contribution
    - float time                       //time in [ns] of this contribution
    - edm4hep::Vector3f stepPosition   //position of this energy deposition (step) [mm]
  OneToOneRelations:
    - edm4hep::MCParticle particle     //primary MCParticle that caused the shower responsible for this contribution to the hit.
```

Backup | edm4hep::SimCalorimeterHit



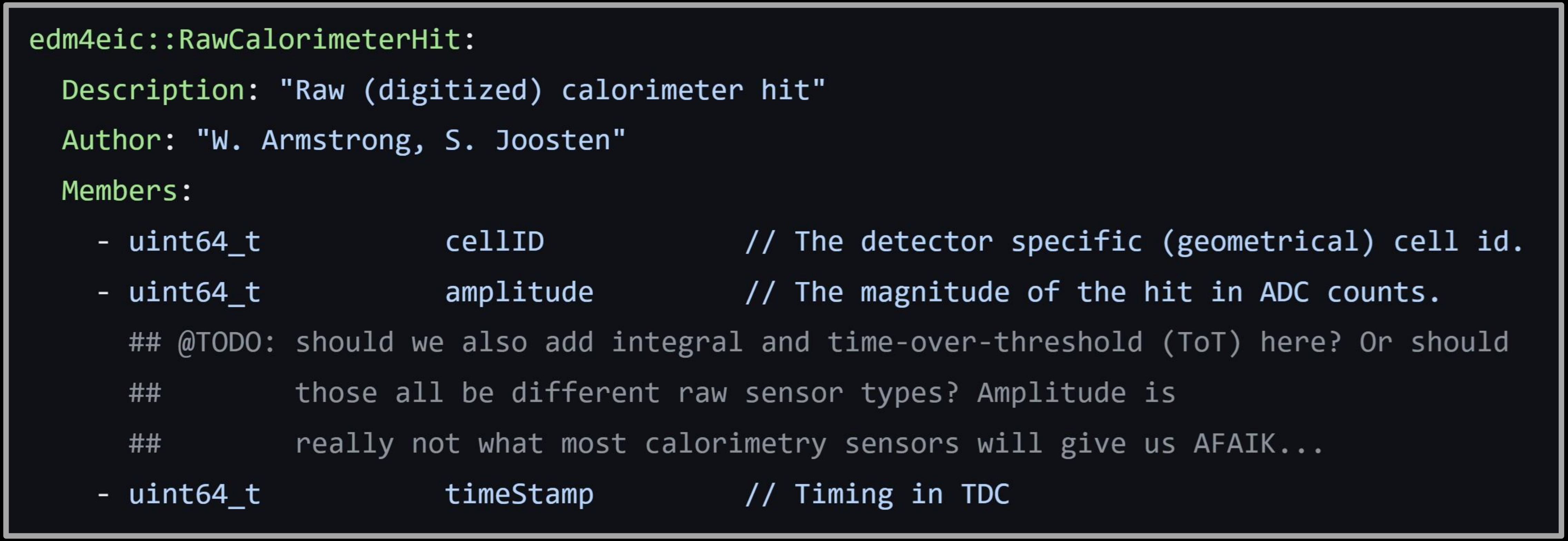
```
#------------- SimCalorimeterHit
edm4hep::SimCalorimeterHit:
  Description: "Simulated calorimeter hit"
  Author: "F.Gaede, DESY"
  Members:
    - uint64_t cellID       //ID of the sensor that created this hit
    - float energy                    //energy of the hit in [GeV].
    - edm4hep::Vector3f position      //position of the hit in world coordinates in [mm].
  OneToManyRelations:
    - edm4hep::CaloHitContribution contributions  //Monte Carlo step contribution - parallel to particle
```

Backup | edm4hep::RawCalorimeterHit



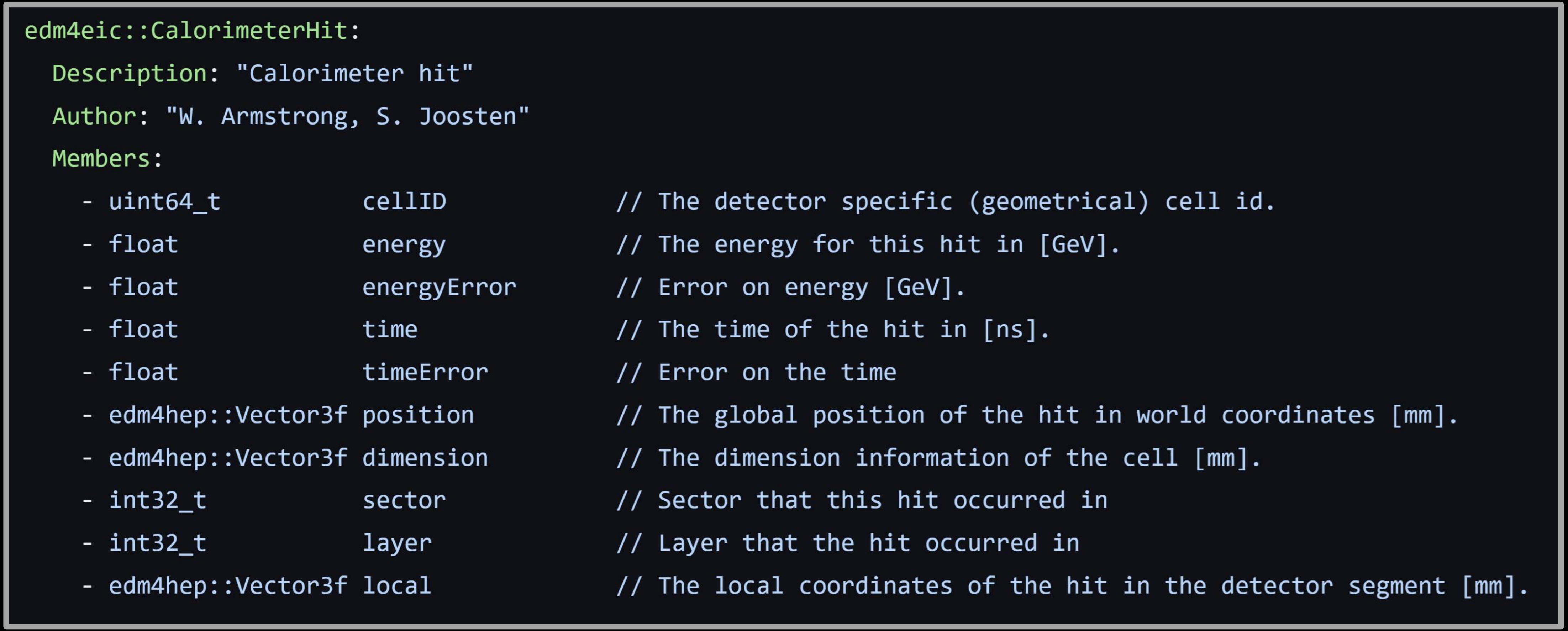
```
#-------------  RawCalorimeterHit
edm4hep::RawCalorimeterHit:
  Description: "Raw calorimeter hit"
  Author: "F.Gaede, DESY"
  Members:
    - uint64_t cellID   //detector specific (geometrical) cell id.
    - int32_t amplitude              //amplitude of the hit in ADC counts.
    - int32_t timeStamp              //time stamp for the hit.
```

Backup | edm4eic::RawCalorimeterHit



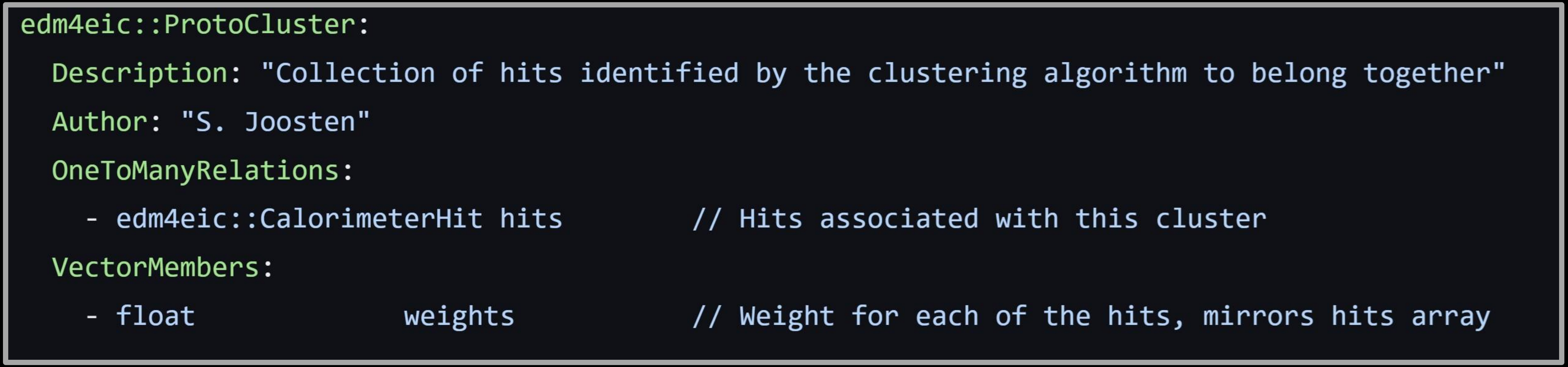
```
edm4eic::RawCalorimeterHit:
  Description: "Raw (digitized) calorimeter hit"
  Author: "W. Armstrong, S. Joosten"
  Members:
    - uint64_t          cellID            // The detector specific (geometrical) cell id.
    - uint64_t          amplitude         // The magnitude of the hit in ADC counts.
      ## @TODO: should we also add integral and time-over-threshold (ToT) here? Or should
      ##        those all be different raw sensor types? Amplitude is
      ##        really not what most calorimetry sensors will give us AFAIK...
    - uint64_t          timeStamp         // Timing in TDC
```

Backup | edm4eic::CalorimeterHit



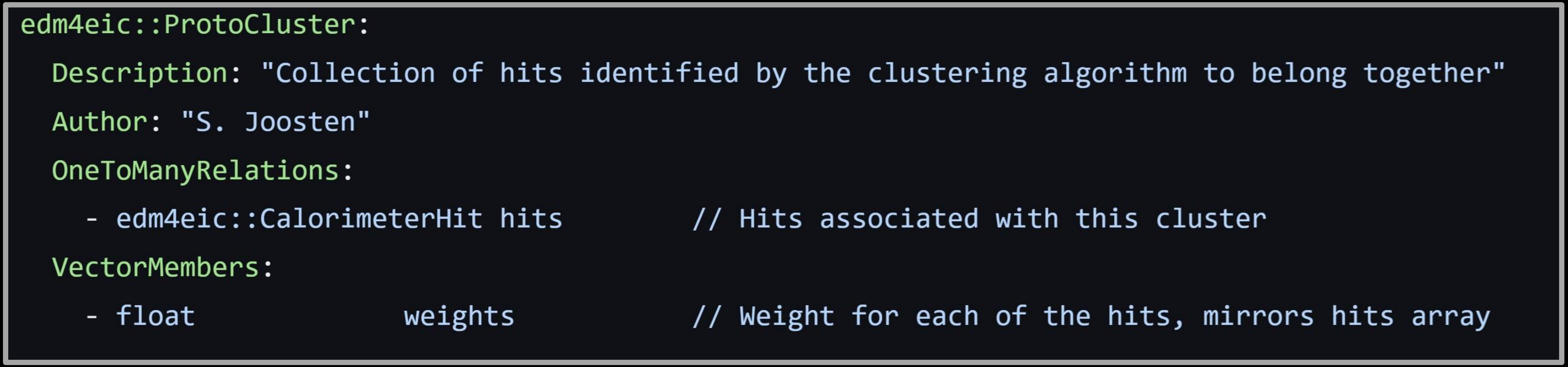
```
edm4eic::CalorimeterHit:
  Description: "Calorimeter hit"
  Author: "W. Armstrong, S. Joosten"
  Members:
    - uint64_t          cellID            // The detector specific (geometrical) cell id.
    - float             energy            // The energy for this hit in [GeV].
    - float             energyError       // Error on energy [GeV].
    - float             time              // The time of the hit in [ns].
    - float             timeError         // Error on the time
    - edm4hep::Vector3f position          // The global position of the hit in world coordinates [mm].
    - edm4hep::Vector3f dimension         // The dimension information of the cell [mm].
    - int32_t           sector            // Sector that this hit occurred in
    - int32_t           layer             // Layer that the hit occurred in
    - edm4hep::Vector3f local             // The local coordinates of the hit in the detector segment [mm].
```

Backup | edm4eic::Protocluster



```
edm4eic::ProtoCluster:
  Description: "Collection of hits identified by the clustering algorithm to belong together"
  Author: "S. Joosten"
  OneToManyRelations:
    - edm4eic::CalorimeterHit hits        // Hits associated with this cluster
  VectorMembers:
    - float             weights           // Weight for each of the hits, mirrors hits array
```

Backup | edm4eic::Protocluster



```
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  OneToManyRelations:
    - edm4eic::CalorimeterHit hits        // Hits associated with this cluster
  VectorMembers:
    - float             weights           // Weight for each of the hits, mirrors hits array
```
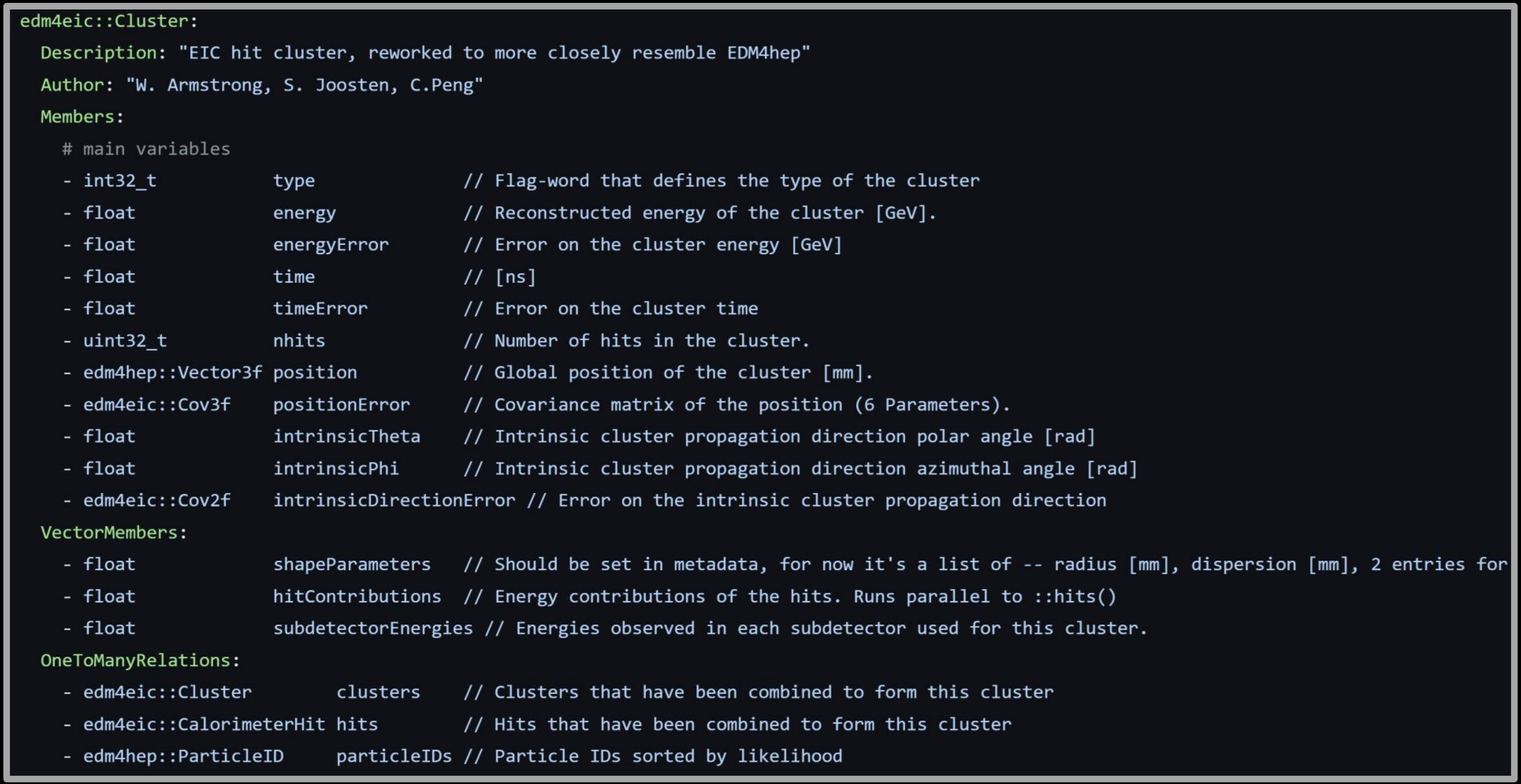
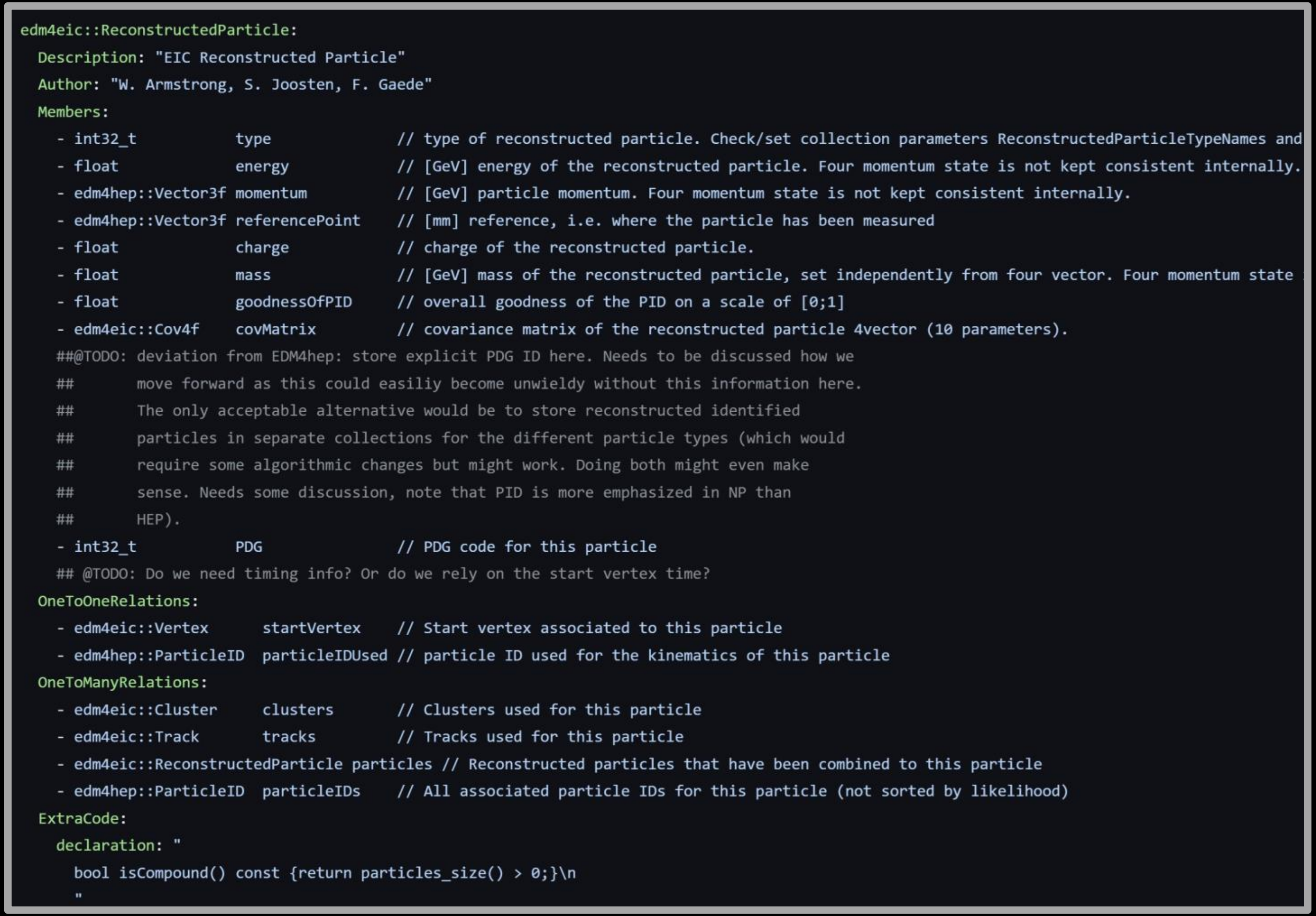

Backup | edm4eic::Cluster



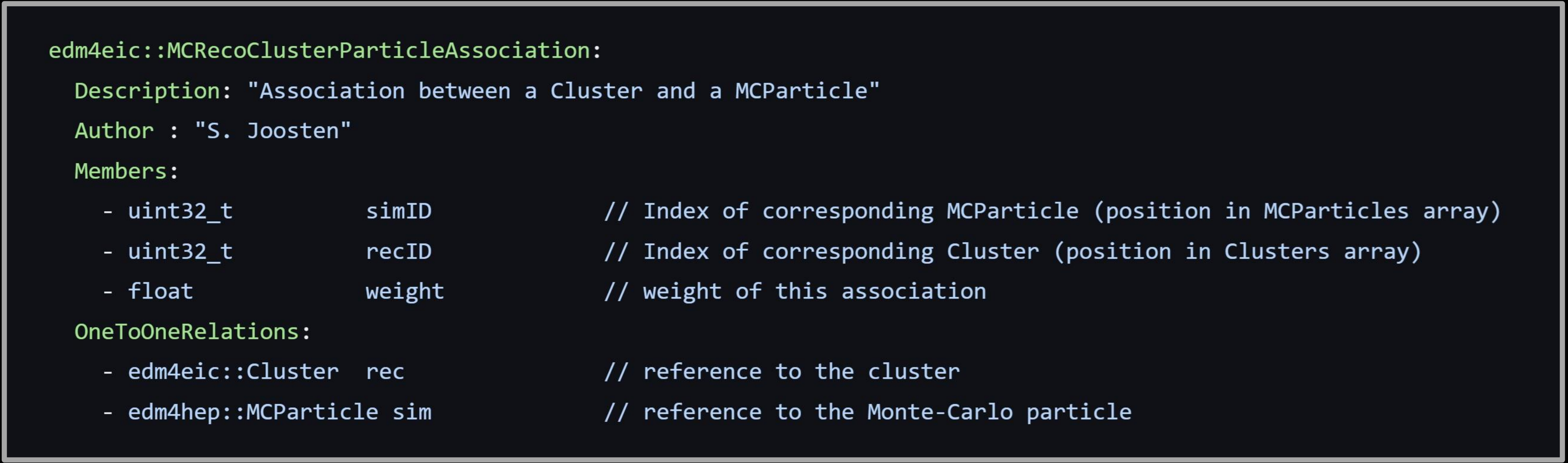
```
edm4eic::Cluster:
  Description: "EIC hit cluster, reworked to more closely resemble EDM4hep"
  Author: "W. Armstrong, S. Joosten, C.Peng"
  Members:
    # main variables
    - int32_t           type              // Flag-word that defines the type of the cluster
    - float             energy            // Reconstructed energy of the cluster [GeV].
    - float             energyError       // Error on the cluster energy [GeV]
    - float             time              // [ns]
    - float             timeError         // Error on the cluster time
    - uint32_t          nhits             // Number of hits in the cluster.
    - edm4hep::Vector3f position          // Global position of the cluster [mm].
    - edm4eic::Cov3f    positionError     // Covariance matrix of the position (6 Parameters).
    - float             intrinsicTheta    // Intrinsic cluster propagation direction polar angle [rad]
    - float             intrinsicPhi      // Intrinsic cluster propagation direction azimuthal angle [rad]
    - edm4eic::Cov2f    intrinsicDirectionError // Error on the intrinsic cluster propagation direction
  VectorMembers:
    - float             shapeParameters   // Should be set in metadata, for now it's a list of -- radius [mm], dispersion [mm], 2 entries for
    - float             hitContributions  // Energy contributions of the hits. Runs parallel to ::hits()
    - float             subdetectorEnergies // Energies observed in each subdetector used for this cluster.
  OneToManyRelations:
    - edm4eic::Cluster        clusters    // Clusters that have been combined to form this cluster
    - edm4eic::CalorimeterHit hits        // Hits that have been combined to form this cluster
    - edm4hep::ParticleID     particleIDs // Particle IDs sorted by likelihood
```

Backup | edm4eic::ReconstructedParticle



```
edm4eic::ReconstructedParticle:
  Description: "EIC Reconstructed Particle"
  Author: "W. Armstrong, S. Joosten, F. Gaede"
  Members:
    - int32_t           type              // type of reconstructed particle. Check/set collection parameters ReconstructedParticleTypeNames and
    - float             energy            // [GeV] energy of the reconstructed particle. Four momentum state is not kept consistent internally.
    - edm4hep::Vector3f momentum          // [GeV] particle momentum. Four momentum state is not kept consistent internally.
    - edm4hep::Vector3f referencePoint    // [mm] reference, i.e. where the particle has been measured
    - float             charge            // charge of the reconstructed particle.
    - float             mass              // [GeV] mass of the reconstructed particle, set independently from four vector. Four momentum state
    - float             goodnessOfPID     // overall goodness of the PID on a scale of [0;1]
    - edm4eic::Cov4f    covMatrix         // covariance matrix of the reconstructed particle 4vector (10 parameters).
    ##@TODO: deviation from EDM4hep: store explicit PDG ID here. Needs to be discussed how we
    ##       move forward as this could easiliy become unwieldy without this information here.
    ##       The only acceptable alternative would be to store reconstructed identified
    ##       particles in separate collections for the different particle types (which would
    ##       require some algorithmic changes but might work. Doing both might even make
    ##       sense. Needs some discussion, note that PID is more emphasized in NP than
    ##       HEP).
    - int32_t           PDG               // PDG code for this particle
    ## @TODO: Do we need timing info? Or do we rely on the start vertex time?
  OneToOneRelations:
    - edm4eic::Vertex      startVertex    // Start vertex associated to this particle
    - edm4hep::ParticleID  particleIDUsed // particle ID used for the kinematics of this particle
  OneToManyRelations:
    - edm4eic::Cluster     clusters       // Clusters used for this particle
    - edm4eic::Track       tracks         // Tracks used for this particle
    - edm4eic::ReconstructedParticle particles // Reconstructed particles that have been combined to this particle
    - edm4hep::ParticleID  particleIDs    // All associated particle IDs for this particle (not sorted by likelihood)
  ExtraCode:
    declaration: "
      bool isCompound() const {return particles_size() > 0;}\n
      "
```

Backup | edm4eic::MCRecoClusterParticleAssoc.



```
edm4eic::MCRecoClusterParticleAssociation:
  Description: "Association between a Cluster and a MCParticle"
  Author : "S. Joosten"
  Members:
    - uint32_t          simID             // Index of corresponding MCParticle (position in MCParticles array)
    - uint32_t          recID             // Index of corresponding Cluster (position in Clusters array)
    - float             weight            // weight of this association
  OneToOneRelations:
    - edm4eic::Cluster  rec               // reference to the cluster
    - edm4hep::MCParticle sim             // reference to the Monte-Carlo particle
```

○ **Note:** seems **to** associates cluster to particle associated with highest energy cell