

Muons in the AOD

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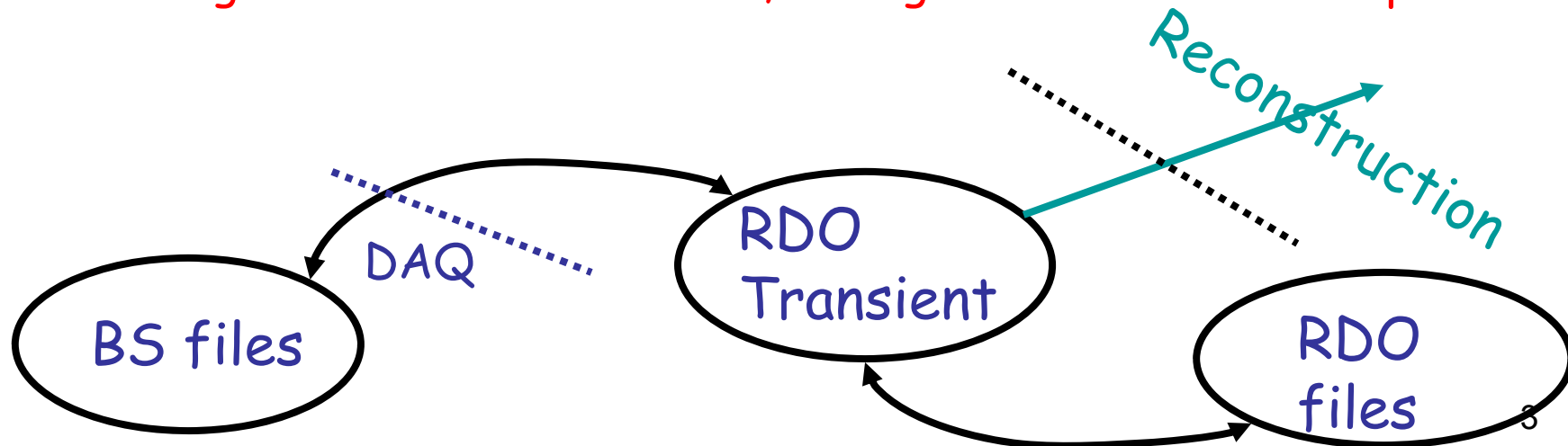
Outline

- Data formats
- AOD contents - release 13.0.30
- Muons in the AOD
- Muon ESD/AOD merger
- Muon re-usable tools on AOD
- Examples
- Changes toward release 14

Data formats

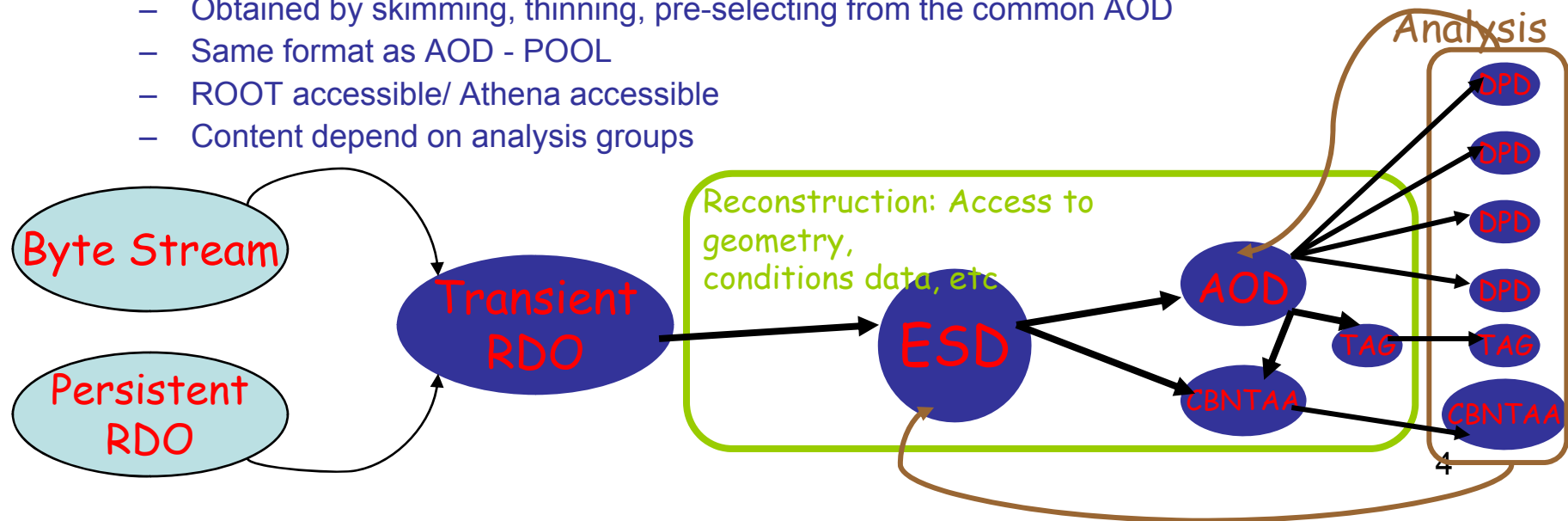
- Byte Stream (BS)
 - It is the output of the electronic readout, e.g., the ADC and TDC values from the muon spectrometer electronics
 - The raw data will be saved in BS - a stream of bits that requires the knowledge of the ROD (Read Out Driver) format for its decoding
- Raw Data Object (RDO)
 - It is the transient representation of the BS
 - But the RDO can be saved - persistified - into the POOL format

Therefore, the raw data can be saved as Byte Stream and/or as persistified RDO in POOL. The RDO offers the possibility of saving the Monte Carlo Truth, during simulation for example



Data formats

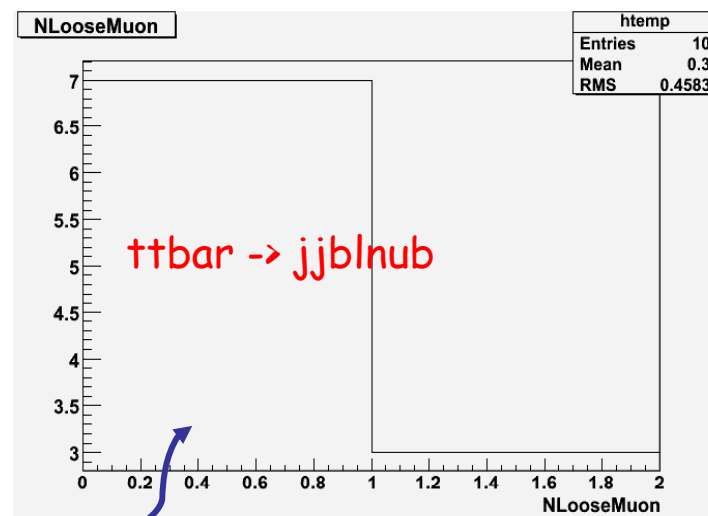
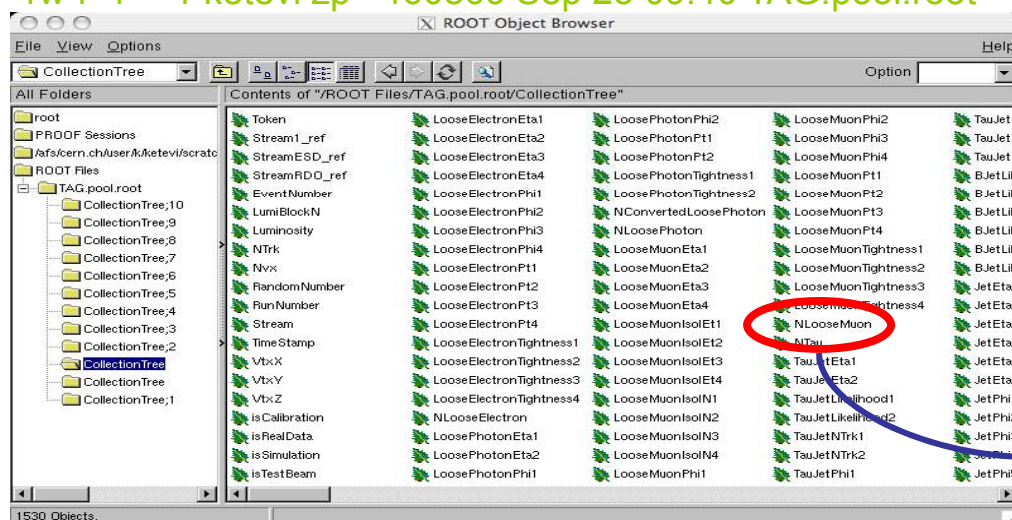
- Event Summary Data (ESD)
 - Reconstruction is done on the BS or the RDO: the output is the ESD
 - ESD contains tracker hits, calorimeter cells, and complex reconstruction output objects such as clusters, track-segments, tracks, jets, loosely identified particles, missing energy
 - Thus ESD useful to redo things (reprocessing) because of better algorithms, better calibration constants, etc, but quite large (~ 1 MB/event) to manipulate for analysis purposes
- Analysis Object Data (AOD)
 - Smaller version of ESD (~10%) with immediate, useful data for analysis
 - Contains loosely identified particles with some overlaps removed, jets, missing energy, calorimeter clusters, track-particles. For some objects (muons, electrons, tau-jets), associated cells, tracker hits, and maybe slimmed tracks are saved in the AOD as well.
- Derived Physics Data (DPD)
 - Obtained by skimming, thinning, pre-selecting from the common AOD
 - Same format as AOD - POOL
 - ROOT accessible/ Athena accessible
 - Content depend on analysis groups



Data formats

- Event Tag (TAG)
 - A very reduced content (~ 1kb/event) of the AOD for a very quick selection of events of interest, e.g., you are interested in final states with 2 jets, an isolated lepton and missing energy
 - You would specify your selection (query) and the events that pass the selection can be copied into a new RDO/ESD/AOD, can be directly analyzed to produce Ntuple or can be passed to the event display
 - There 2 technologies for the TAG
 - As a ROOT file just like aa Ntuple → You can open the TAG ROOT in ROOT and browse it
 - As a relational database, the TAG database
- Athena-Aware NTuple (AAN or AANT) / Combined NTuple Athena-Aware (CBNTAA)
 - ROOT Tuple with TAG functionality for event selection
 - Athena-Aware in the sense of the TAG but not in the sense of the AOD

```
-rw-r--r-- 1 ketevi zp 6254466 Sep 23 09:40 AOD.pool.root
-rw-r--r-- 1 ketevi zp 15360744 Sep 23 09:40 ESD.pool.root
-rw-r--r-- 1 ketevi zp 460869 Sep 23 09:40 TAG.pool.root
```



AOD Content

- The data in the RDO/ESD/AOD files is organized into collections (containers) - essentially a list - of objects, e.g.
 - Container of Muonboy muons candidates
 - Container of MOORE Tracks
- But there also "standalone objects"
 - Muon component of Missing ET, Missing Et Calo, etc
 - Event information
 - Etc
- You need to know the Container/Object Type and Key to be able to use it in your analysis:

```
MuonContainer* muonTDS=0;
m_storeGate->retrieve(muonTDS,"StacoMuonCollection");
```

_p1: persistent version

Memory size	disk Size	Size	disk size/event	N_event	Container_type and key
94.744 kb	0.000 kb	0.000 kb	10	MuonContainer_p1_AtIfastMuonCollection	
94.122 kb	0.000 kb	0.000 kb	10	MuonContainer_p1_AtIfastNonIsoMuonCollection	
99.096 kb	0.000 kb	0.000 kb	10	MuonContainer_p1_CaloMuonCollection	
98.834 kb	0.000 kb	0.000 kb	10	MuonContainer_p1_MuidMuonCollection	
98.760 kb	0.000 kb	0.000 kb	10	MuonContainer_p1_StacoMuonCollection	
10.219 kb	0.000 kb	0.000 kb	10	MissingET_p1_ObjMET_Final	
10.219 kb	0.000 kb	0.000 kb	10	MissingET_p1_ObjMET_Muon	

AOD Content

- The Container or Collection is usually a DataVector of the contained objects:

```
class MuonContainer : public DataVector<Analysis::Muon>
```

- A DataVector is just like an std::vector, with the difference that, by default, the DataVector "owns" its objects:

DataVector<Muon> ≡ std::vector<Muon*>

If the MuonContainer is deleted, all the muon objects pointed to inside the MuonContainer are also deleted

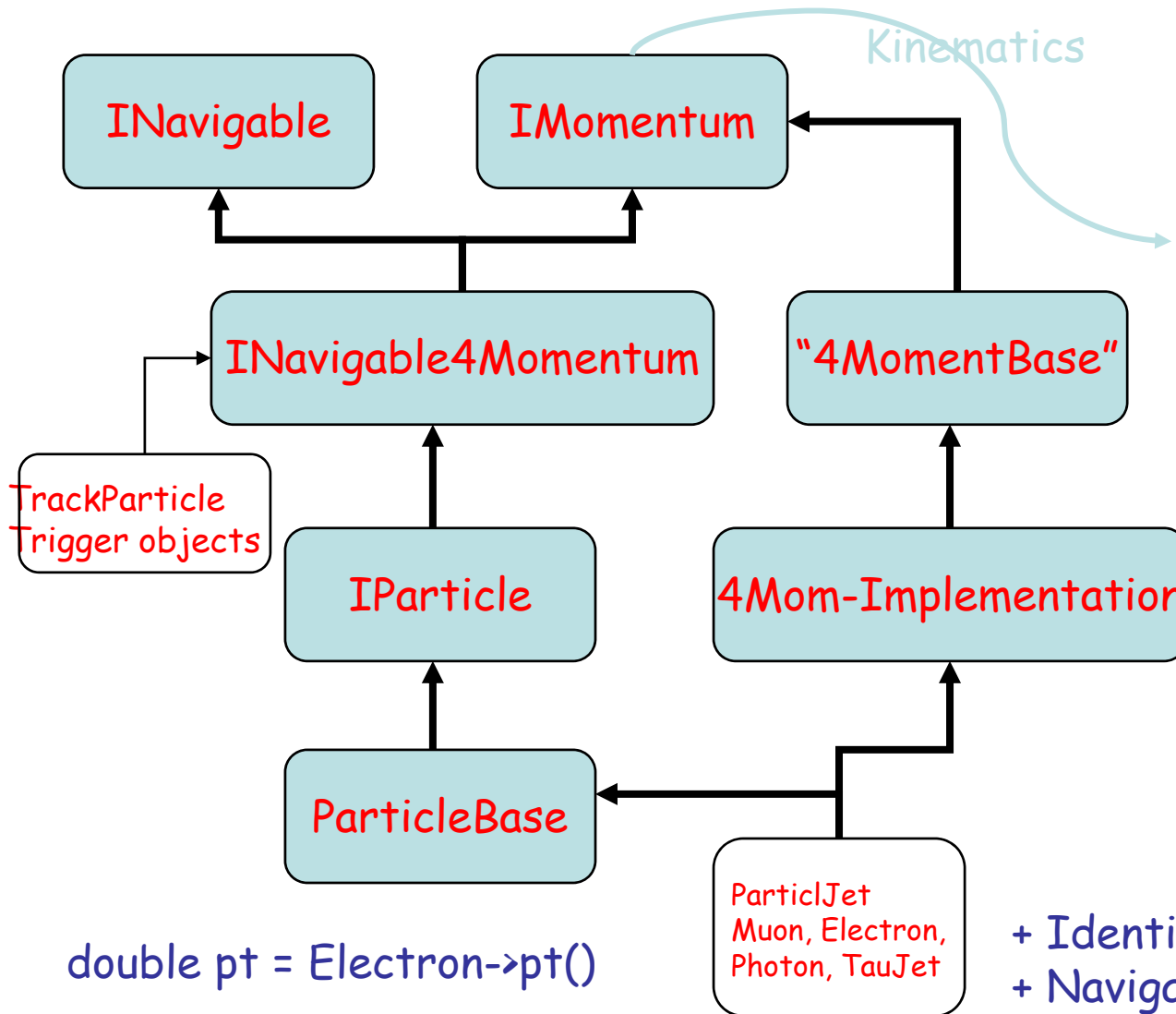
- **Since MuonContainer is just like std::vector<Muon*>, you can use all the methods of std::vector<T*> on the AOD collections**

```
const MuonContainer* muonTDS=0;
StatusCode sc = m_storeGate->retrieve(muonTDS, "StacoMuonCollection");
if (sc.isFailure() {
    mLog << MGS::WARNING << "StacoMuonCollection not found in AOD" << endreq;
    return StatusCode::RECOVERABLE;
}
MuonContainer::const_iterator muonItr = muonTDS->begin();
MuonContainer::const_iterator muonItrE = muonTDS->end();
for (; muonItr != muonItrE; ++muonItr) {
    double muonPt = (*muonItr)->pt();
    ...
}
```

It is possible to create a DataVector<T> that by default does not "own" the T*

AOD Objects

- Particle-like objects (Electron, Photon, Muon), TauJet and ParticleJet in the AOD have a common interface for tools



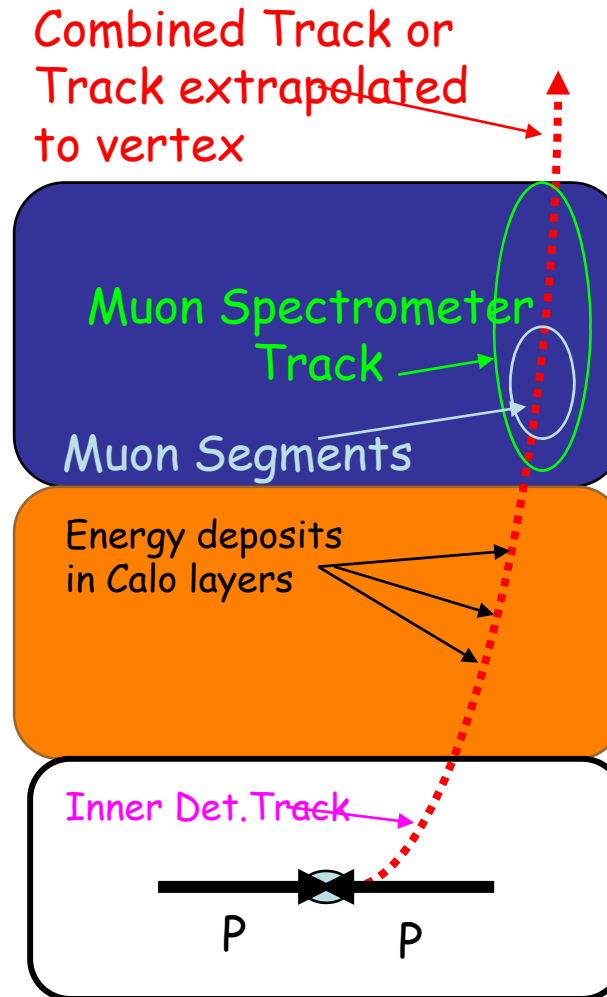
```

/** x component of momentum */
double px() const;
/** y component of momentum */
double py() const;
/** z component of momentum */
double pz() const;
/** mass */
double m() const;
/** mass squared */
double m2() const;
/** momentum magnitude */
double p() const;
/** square of momentum magnitude */
double p2() const;
/** pseudo rapidity */
double eta() const;
/** phi in [-pi,pi] */
double phi() const;
/** energy */
double e() const;
/** transverse energy */
double et() const;
/** transverse momentum */
double pt() const;
/** inverse of Pt */
double iPt();
/** cosinus theta */
double cosTh();
/** sinus theta */
double sinTh() const;
/** cottan theta */
double cotTh() const;
/** CLHEP HepLorentzVector */
HepLorentzVector hlv() const;
  
```

+ Identification Parameters₈
+ Navigation Links

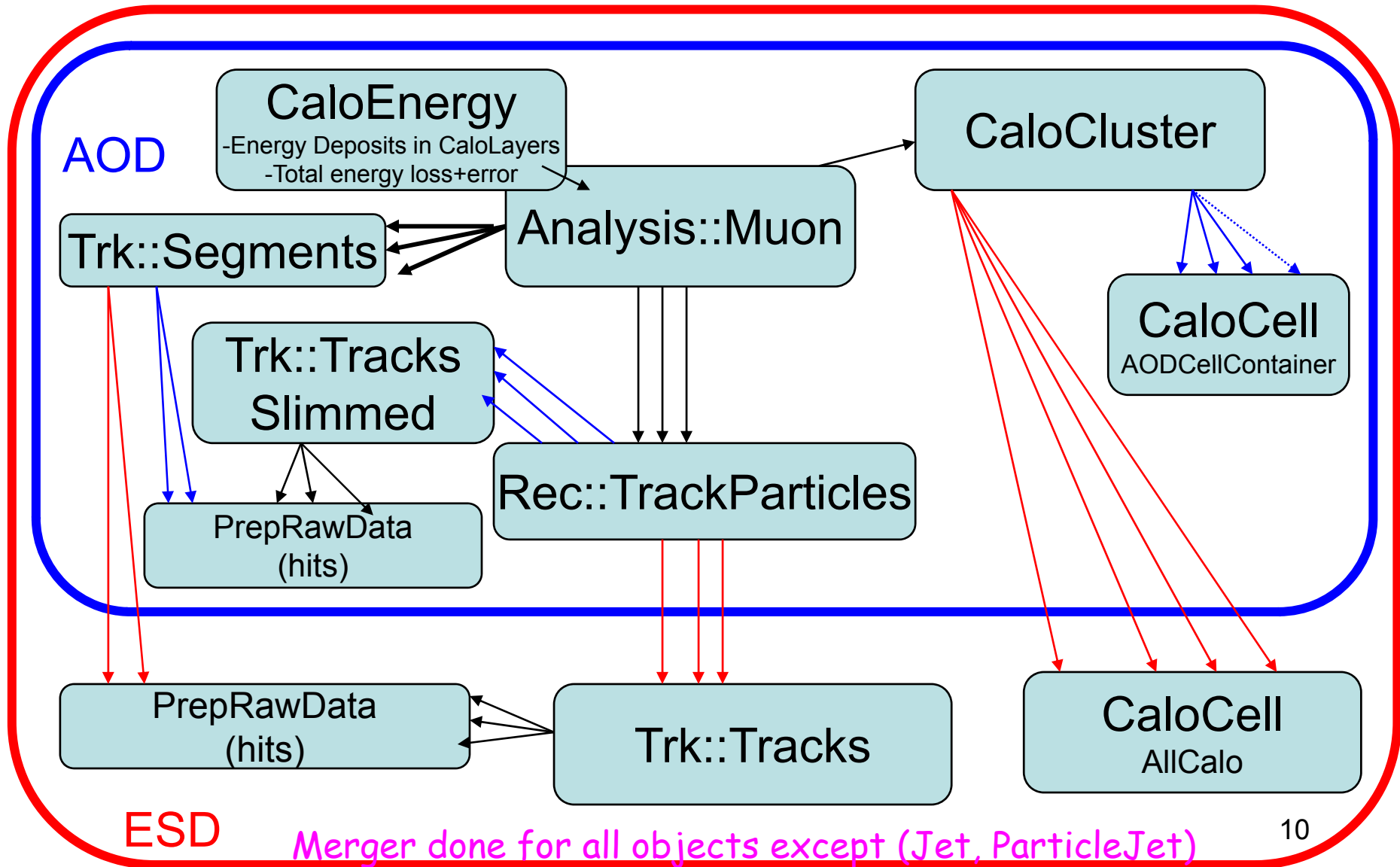
The Muon Object in ESD or AOD

- The Muon is an association of various Tracks in addition to Calorimeter information:
 - Link to Inner Det. TrackParticle
 - Link to Muon Spect. TrackParticle
 - Link to Combined TrackParticle
 - Links to Muon Segments
 - Calo Isolation ET in cones 0.1 to 0.7 (including 0.45)
 - Track isolation in cones 0.1 to 0.7 (including 0.45)
 - CaloEnergy
 - Energy deposited in various Calo layers
 - Parameterized energy loss or measured energy loss
- The TrackParticle maintains a link to the Slimmed Track in the AOD or the full Track in the ESD
- The charge of the Muon is given by the charge of its primary track
- The 4-momentum of the Muon is given by the 4-momentum of the primary track at the beam perigee
- The primary track - by order or precedence - is:
 - The combined track (Inner Det., Muon Spect.) if the combined fit is successful
 - The extrapolated track to the beam perigee if there no combined track
 - The Inner Detector Track in case low Pt muons

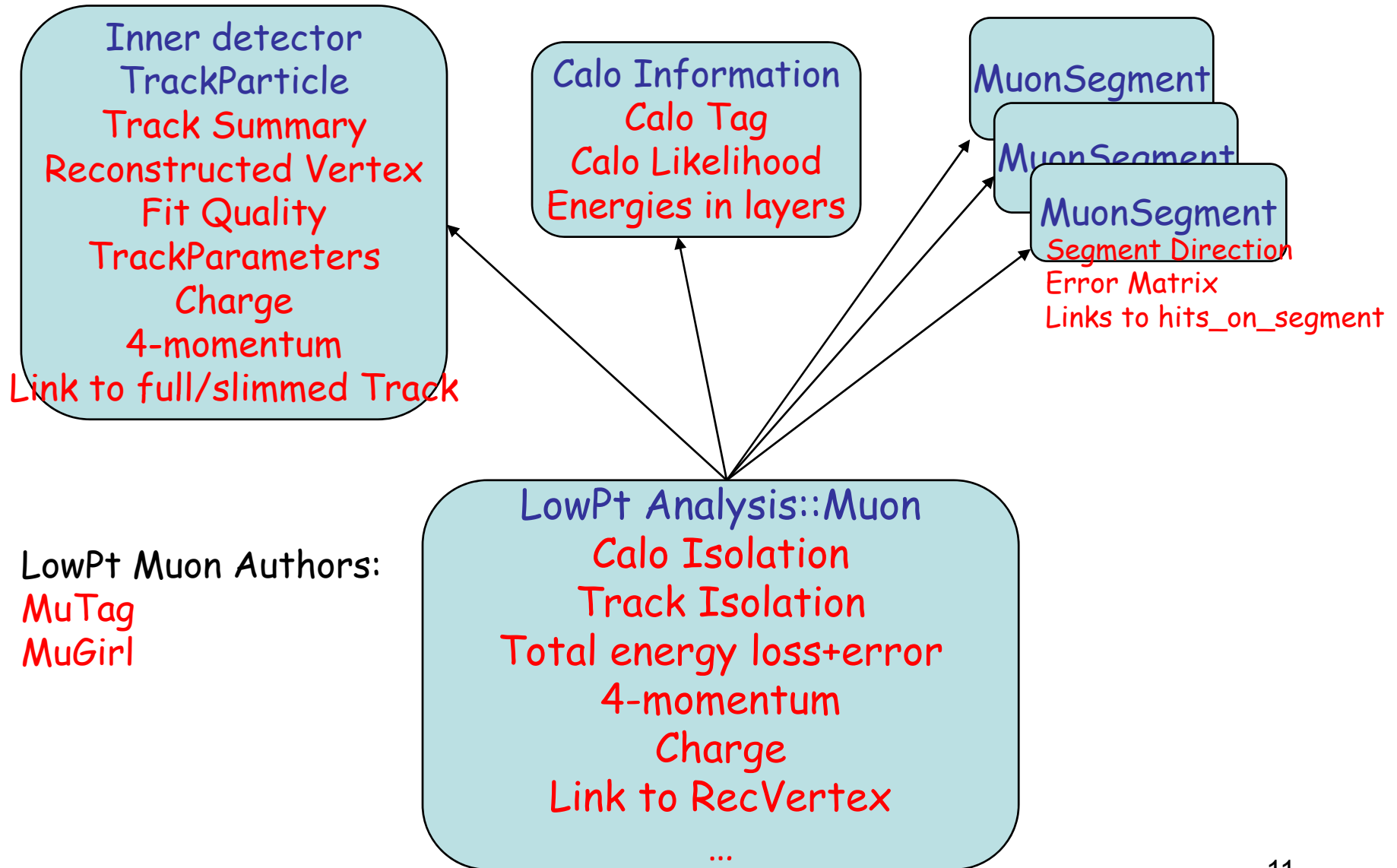


ESD/AOD Merger

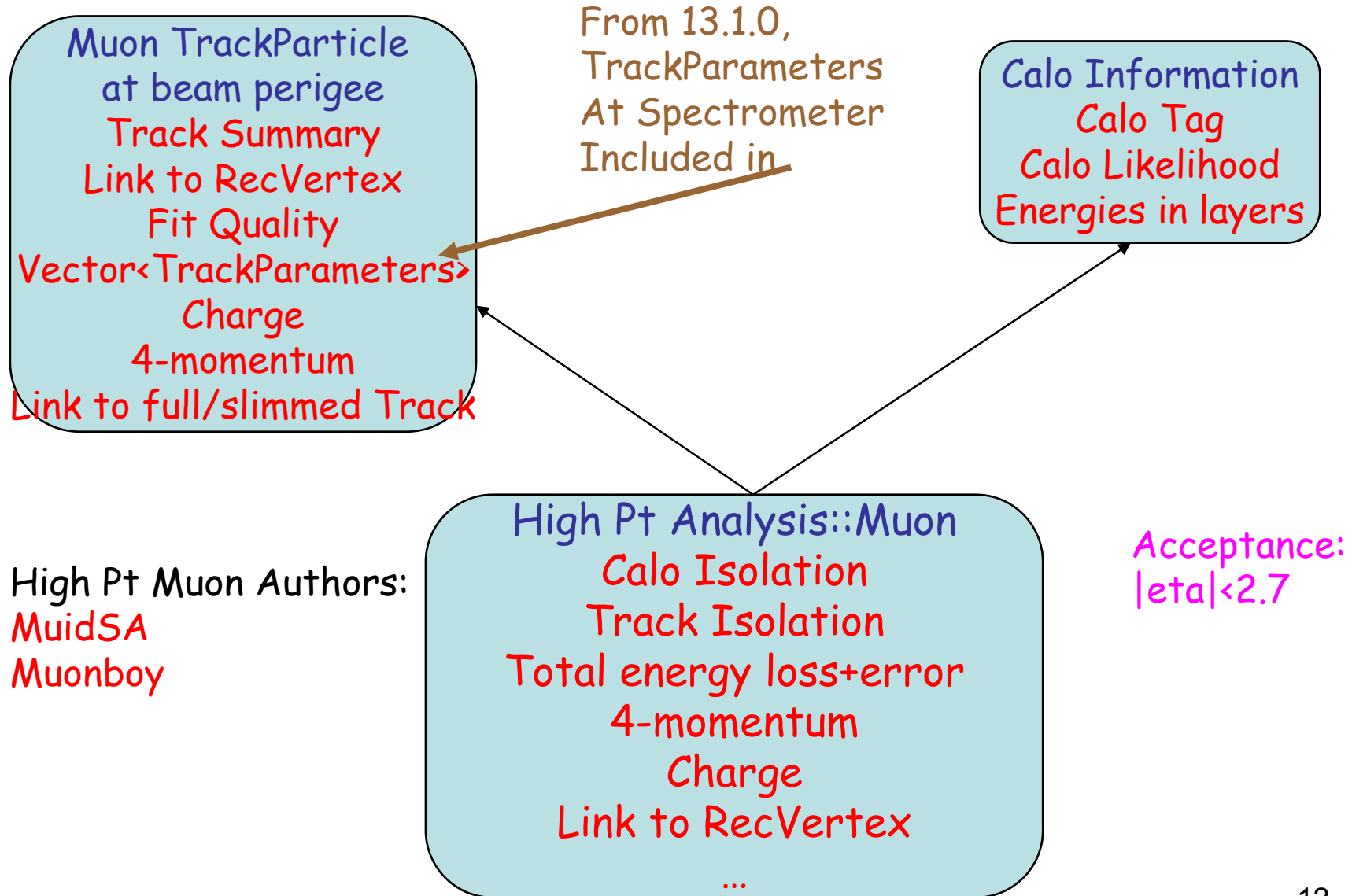
- The idea is to use the same class in the ESD as in the AOD
 - the ESD may have more information than the AOD
 - But your analysis code can run transparently on the AOD or the ESD, perhaps just job options modifications



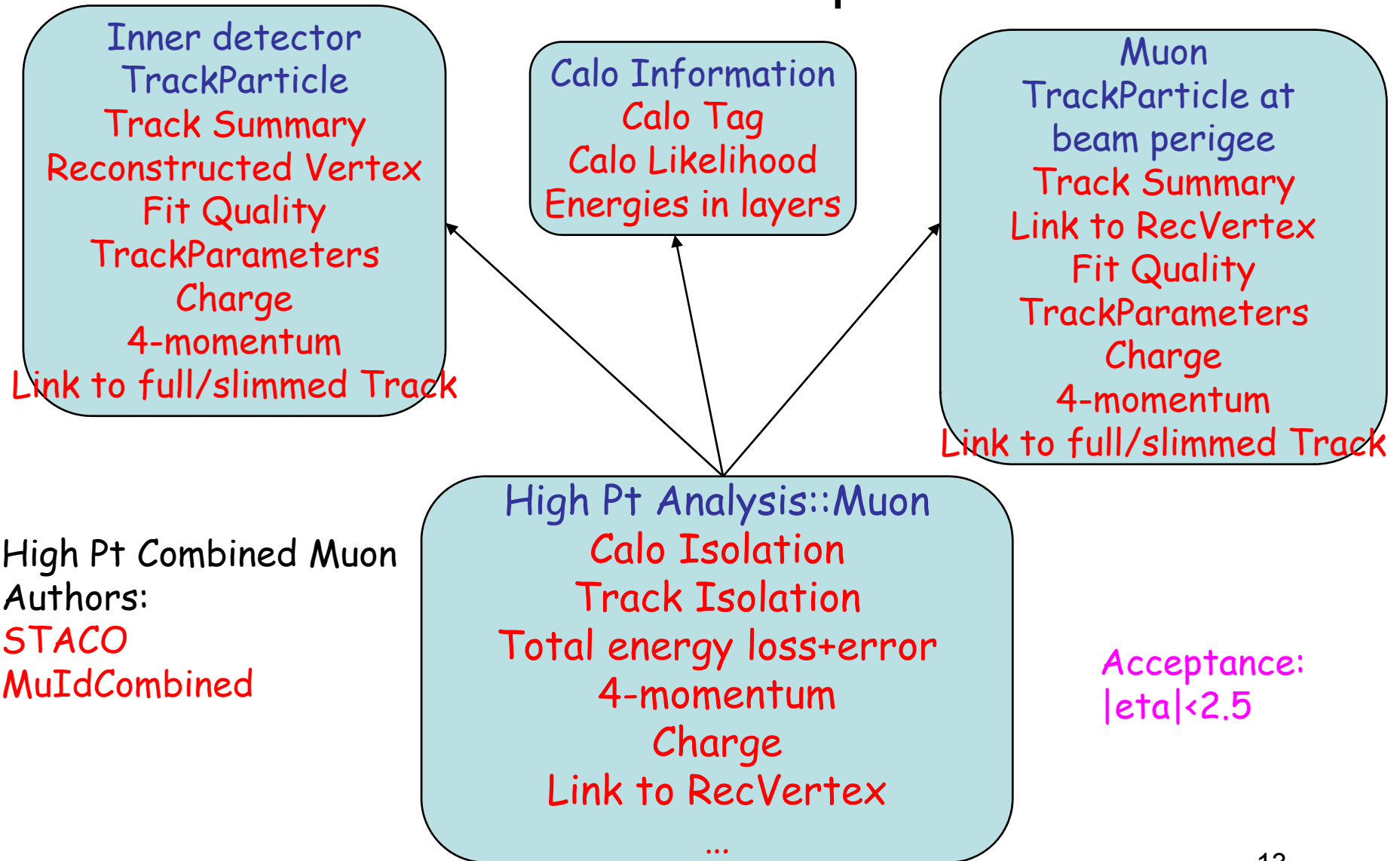
Muon Types - LowPt Muons



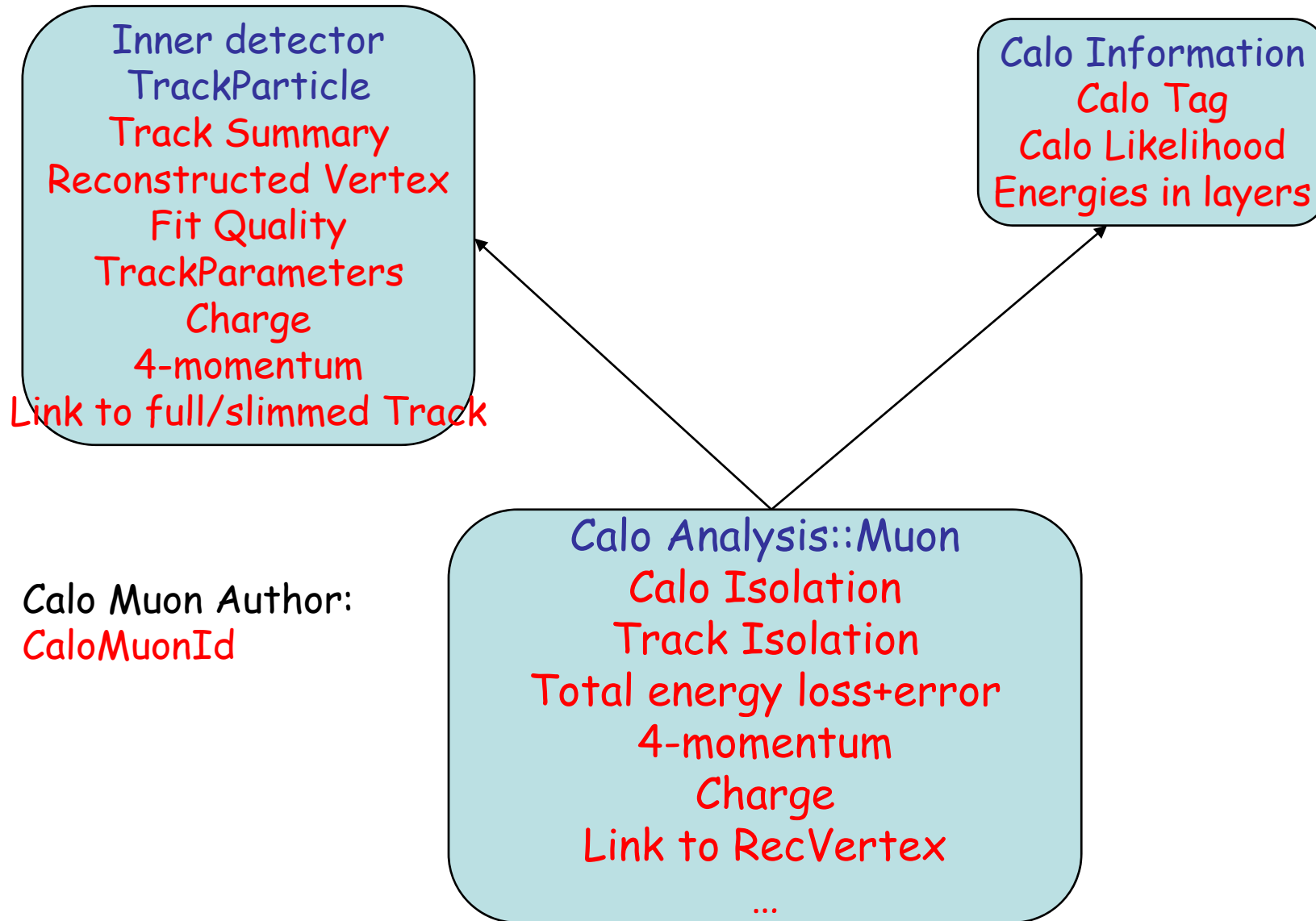
Muon Types - high Pt muons - Extrapolated to beam perigee



Muon Types - Combined Muons - Inner Detector and Muon Spectrometer

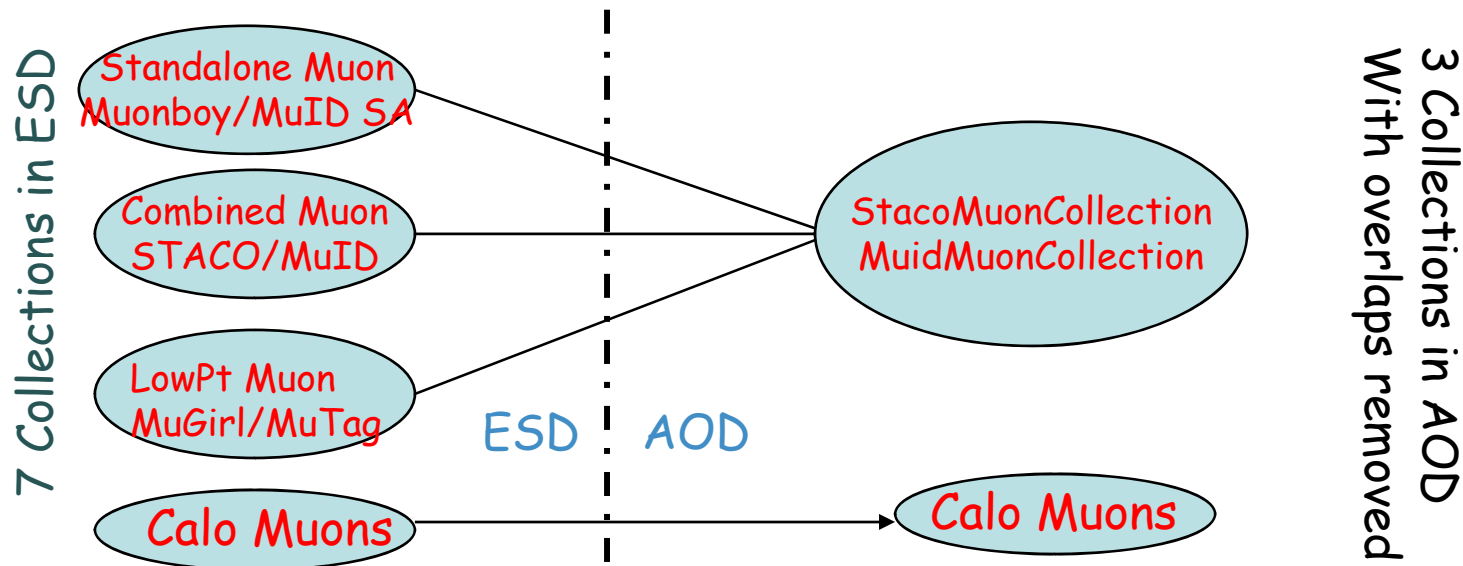


Calorimeter Muons



Muon Reconstruction

- There are 7 combined muon reconstruction algorithms running at the ESD, each producing its own collection of muon candidates. Thus, 7 muon containers in ESD:
 - MuID Standalone (MuID SA)
 - MuID Combined
 - MuGirl
 - Muonboy
 - STACO
 - MuTag
 - CaloTrkMuID --> Calorimeter Muon Identification
- In the AOD, 3 muon containers:
 - MuID SA, MuID and MuGirl go into one container: “MuidMuonCollection”
 - Muonboy, STACO, MuTag go into another rmuon container: “StacoMuonCollection”
 - CaloTrkMuID goes into a separate container: “CaloMuonCollection”

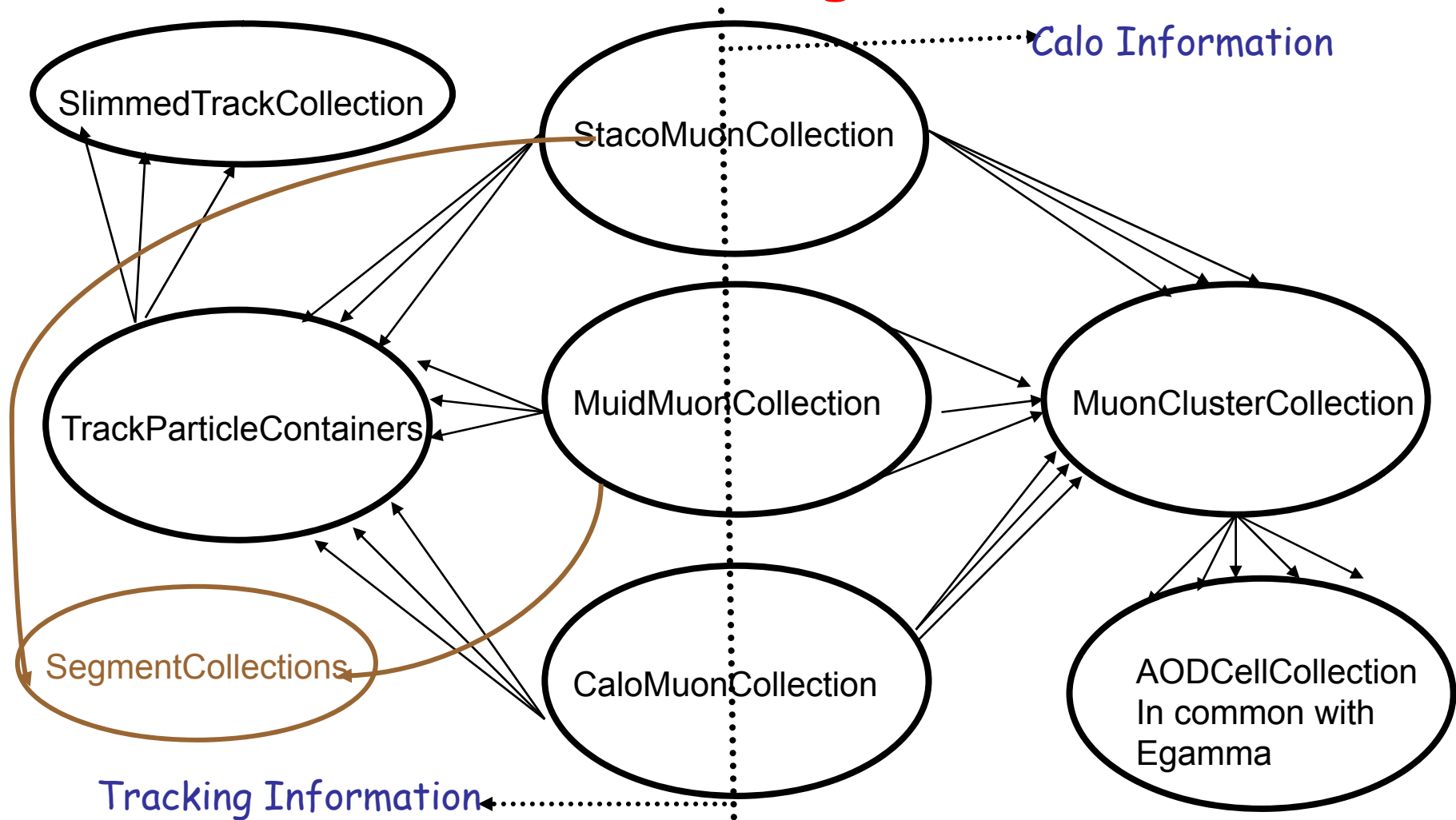


Status of Muon in ESD/AOD - from Release 13.0.30

- These data items are now filled for all muon candidates in ESD/AOD from release 13.0.30
 - Calorimeter cells along the track and nearby-by CaloCells
 - Calorimeter cluster of cells
 - Energy deposits in the Calorimeter layers
 - A muon likelihood based on Calorimeter/Track information
 - A muon tag parameter also based on Calorimeter/Track information
 - A collection of slimmed Tracks associated to the muon for the AOD. The ESD keeps the full Tracks. The slimmed Track allows to have muon detector hits in the AOD

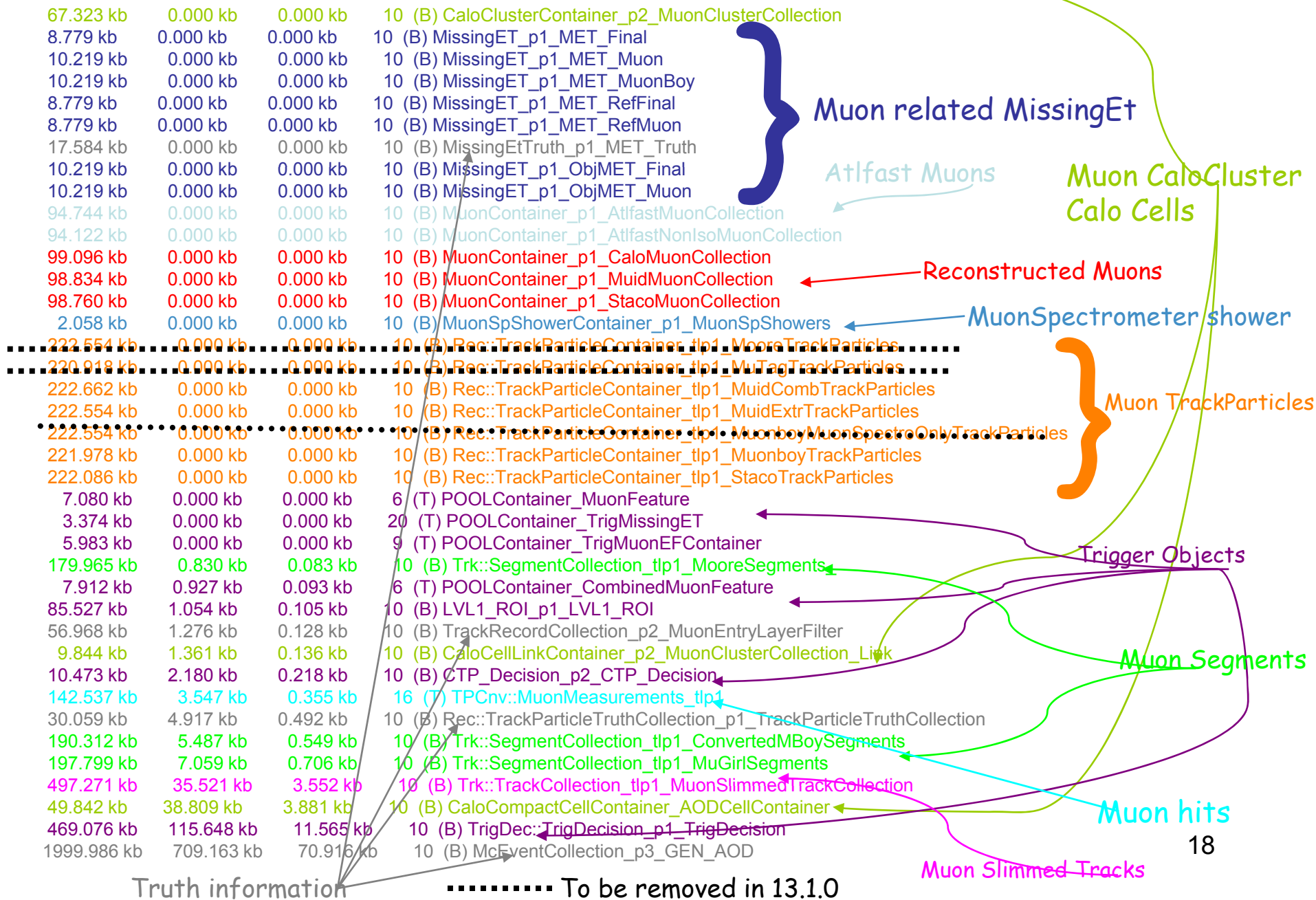
We have CaloCells in the AOD for Electron/Photon and TauJets as well!

Muon in the AOD- Navigation Structure



In the ESD, “AODCellCollection” —> “AllCalo”
Slimmed Track —> Track

Muon Information in AOD



Re-usability of certain tools on the AOD

- See the PAT workshop in Bergen for details -
 - Read in AOD
 - Recalibrate certain objects (e.g. electrons and jets)
 - Rerun high-level reco algorithms (e.g. b-tag, refit e/m tracks, jets)
 - Possibly write out revised AOD collections
 - Reselect physics objects of interest (e.g. loose e, tight m, medium t...)
 - Recompute E_T^{miss} (E_T^{miss} code thus appears as the only one tightly coupled to analysis)
 - Continue with analysis
- Much of this should be possible now on the AOD in release 13
 - Need slimmed tracks and CaloCells for certain objects (egamma, muon, tau) in the AOD
 - Need to be able to rerun certain high level reco algorithms on the AOD
 - Requirements on the core software, e.g., to be able to version AOD collections of same type
 - ...

Muon "Dressing" Tools

K. Bachas, L. Flores, S. Hassani, D. Mateo, G. O. Sanz and KAA
Calorimeter Identification CSC note in preparation

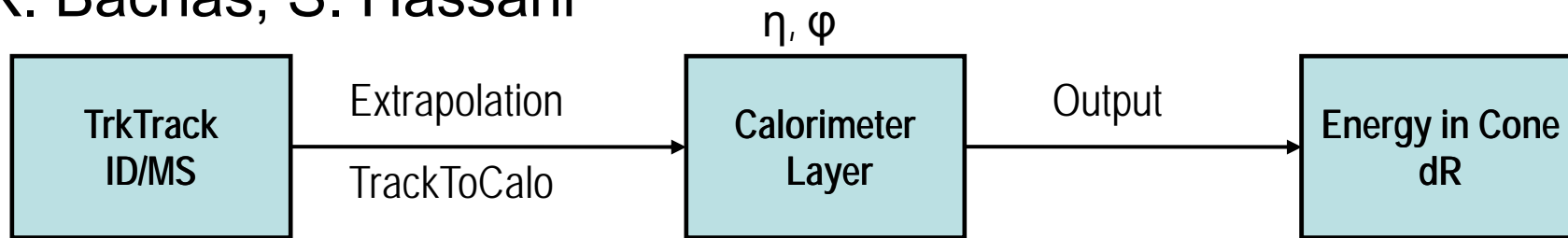
- Muon dressing tools
 - Muon IsolationTool
 - TrackIsolationTool
 - CaloMuonTagTool
 - CaloMuonLikelihoodTool
 - TrackInCaloTool
 - ...
- Objectives
 - All the muon reconstruction algorithms are using the same tools to dressing their muon candidates - no need to copy and proliferate same pieces of codes everywhere.
 - Must be re-usable on the AOD, with job options modifications
 - Integrated into a common framework, no duplication of functionalities/efforts
 - TrackInCaloTool and TrackIsolationTool generic enough for any track including egamma tracks
 - TrackIsolationTool can also do Calo Isolation, even on AOD for any track - job options adjustments of CaloCell weights

Muon Dressing Tools

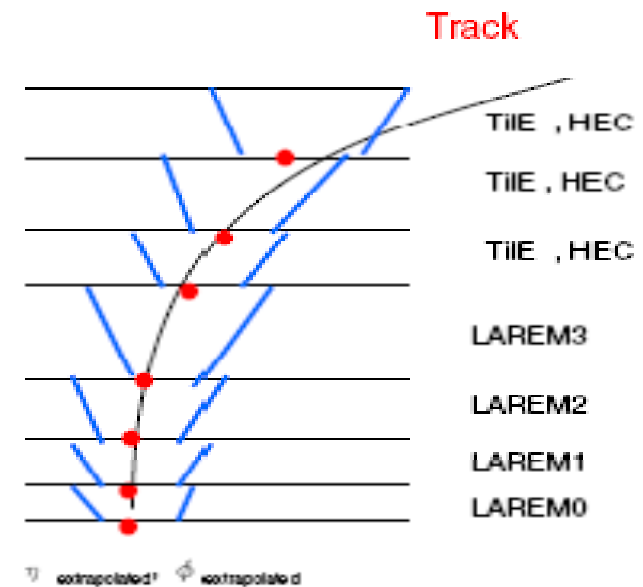
- After the combined muon reconstruction, the Analysis::Muon is passed to the “dressing” tools which fill this information:
 - Calo Isolation
 - Track Isolation
 - Energy deposits in Calo layers
 - Calo muon Tag
 - Calo muon likelihood
 - Muon CaloCluster
 - Muon CaloCells
- All muon candidates from the 7 muon reconstruction algorithms carry this information to the AOD
 - Muonboy, STACO, MuTag → StacoMuonCollection
 - MuID SA, MuID Combined, MuGirl → MuidMuonCollection
 - CaloTrkMuID → CaloMuonCollection

TrackInCaloTool

K. Bachas, S. Hassani



1. Start from MS/ID track
2. Use TrackToCalo Tool to extrapolate the track to the desired Calorimeter Layer.
3. Get track η and ϕ on sampling from extrapolator
4. Sum up the cell energy deposited
 - a) In rectangular or circular cone sizes of any size
 - b) Cell noise taken into account using CaloNoiseTool
5. Repeat steps 2 to 4 for other calo samplings
6. Provide energy loss measurements
7. Return the list of muon CaloCells
8. Basis for Calo Isolation



TrackIsolationTool/MuonIsolationTool

K. Bachas, S. Hassani, KAA

- Can be used on ESD or AOD - generic for any track
- On the ESD, it can also do Calo isolation
- With muon and egamma cells on AOD, TrackIsolationTool allows to recompute Calo Isolation on AOD
- MuonIsolationTool and TrackIsolationTool both derive from IIsolationTool. MuonIsolationTool simply accounts for the muon energy loss in Calo for Calo isolation
- With the muon CaloCells on the AOD, MuonIsolationTool can also be re-used on the AOD for muon Calo Isolation

CaloMuonTag/CaloMuonLikelihoodTool

- **CaMuonTagTool** - fully re-usable on AOD - G. O. Sanz
 - Identifies 3 regions in eta for track extrapolation:
 - 1. Eta <1.5 Barrel: TileBar or TileExt or TileGap (ITC) for 3 layers
 - 2. 1.5<Eta<1.7 Crack: TileExt or HEC for 2 layers. There is not 3rd layer in this region
 - 3. Eta>1.7 End-cap: HEC for last 3 layers
 - If the extrapolation is successful, it gets the cell (only one) closer to the it and gets the energy deposited in such cell. Applies threshold cuts according to track length in the given Calorimeter sample. Calculate parameterized energy loss. After this, the track is tagged following this schema, in the last 3 layers of the HEC:
 - 0 Not a muon
 - 1 Muon tagged with deposit in last layer of Calo
 - 2 Muon tagged with deposit in last-1 layer
 - 3 Muon tagged with deposit in last-2 layer
- **CaloMuonLikelihoodTool** - L. Flores et al.
 - Tool provides additional muon quality information - muon/pion likelihood ratio - based on InDet Track and all calorimeter information. Returned Likelihood between 0 and 1
 - Tool requires CaloTopoClusters 4-2-0, not available in the AOD. **Tool therefore not re-usable on the AOD**

Reusable tools on AOD

- With the CaloCells and Hits on the AOD, many tools that operate only on the ESD can now be re-used on the AOD. Thus the following stage 0 analysis now possible on the AOD:
 - Recompute Electron/Photon/Muon/TauJet identification parameters
 - Refit muon/egamma tracks
 - Recalculate Calorimeter isolation
 - Check for overlap at hit and cell levels
 - Redoing b-tagging, track extrapolation, track isolation, jet reconstruction on AOD already viable before
- Can we then rerun the muon combined reconstruction, e.g., STACO, on the AOD, possibly output a new collection of re-fitted/re-calibrated muons?

Documentation and Examples

- PhysicsAnalysisTools: <https://twiki.cern.ch/twiki/bin/view/Atlas/PhysicsAnalysisTools>
- ATLAS workbook: <https://twiki.cern.ch/twiki/bin/view/Atlas/WorkBook>
- Jet: <https://twiki.cern.ch/twiki/bin/view/Atlas/JetsReRunning>
- Egamma: <https://twiki.cern.ch/twiki/bin/view/Atlas/EgammaATLASRecoPerformance>
- Physics Analysis Work Book: <https://twiki.cern.ch/twiki/bin/view/Atlas/PhysicsAnalysisWorkBook>
- Tau Analysis: <https://twiki.cern.ch/twiki/bin/view/Atlas/TauAnalysis>
- Analysis Examples: <http://atlas-sw.cern.ch/cgi-bin/viewcvs-atlas.cgi/offline/PhysicsAnalysis/AnalysisCommon/AnalysisExamples/>
- Analysis Skeleton: <http://atlas-sw.cern.ch/cgi-bin/viewcvs-atlas.cgi/offline/PhysicsAnalysis/AnalysisCommon/UserAnalysis/>
- EventView: <https://twiki.cern.ch/twiki/bin/view/Atlas/EventView>
- CaloClusters: <https://twiki.cern.ch/twiki/bin/view/Atlas/CaloClustering>
- Muons: <https://twiki.cern.ch/twiki/bin/view/Atlas/MuonSoftware>
- Jets in AOD: <https://twiki.cern.ch/twiki/bin/view/Atlas/JetsInAOD>
- Trigger: <https://twiki.cern.ch/twiki/bin/view/Atlas/TriggerEDM>
- Tau Reconstruction: <https://twiki.cern.ch/twiki/bin/view/Atlas/TauRec>
- Flavor Tagging: <https://twiki.cern.ch/twiki/bin/view/Atlas/FlavourTagging>
- Tracks: <https://twiki.cern.ch/twiki/bin/view/Atlas/TrackingEDM>