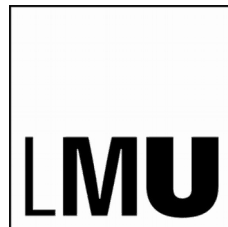




Missing TransvErse MomenTum

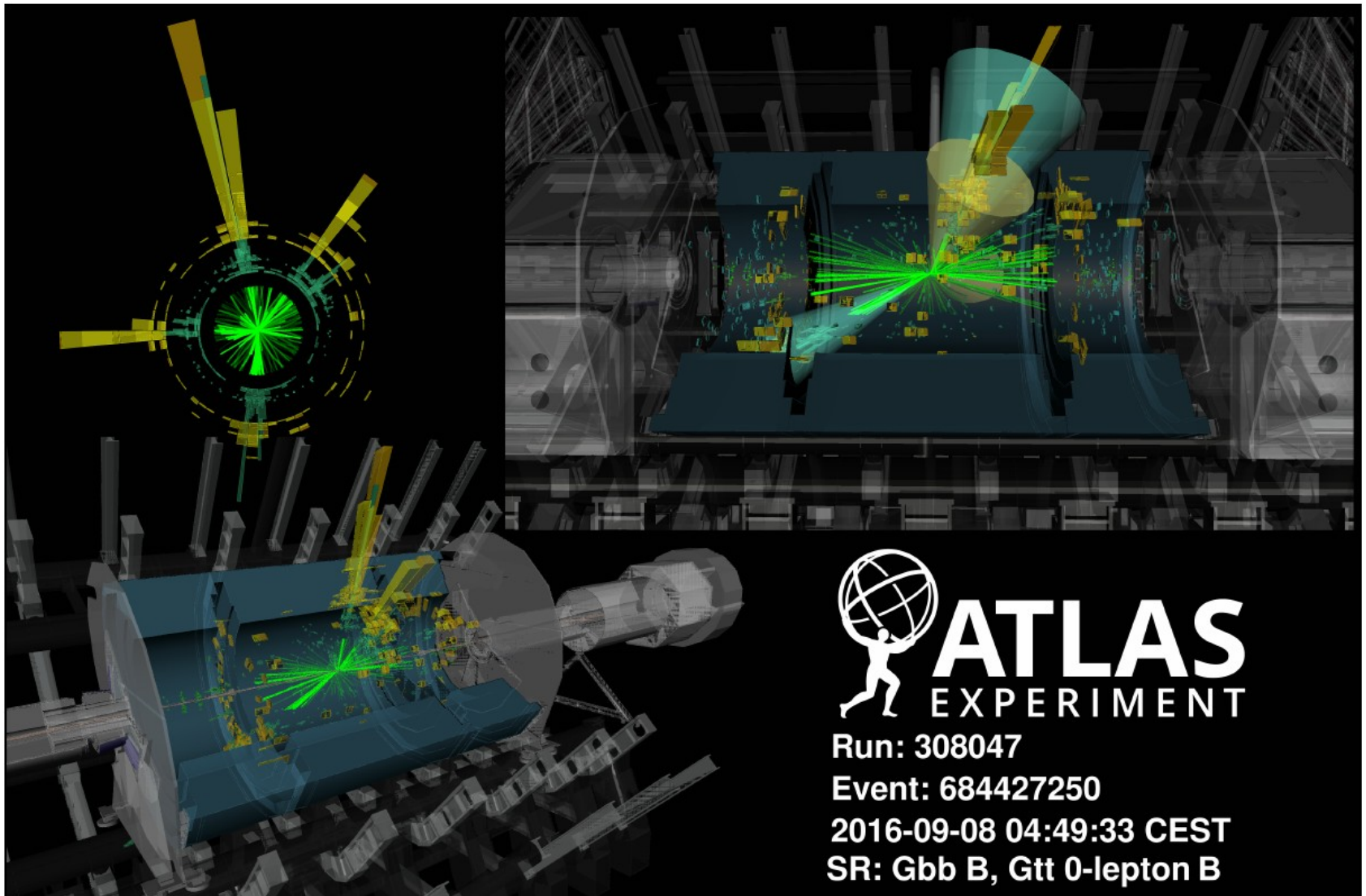
Jeanette Lorenz *on behalf of the MET subgroup*



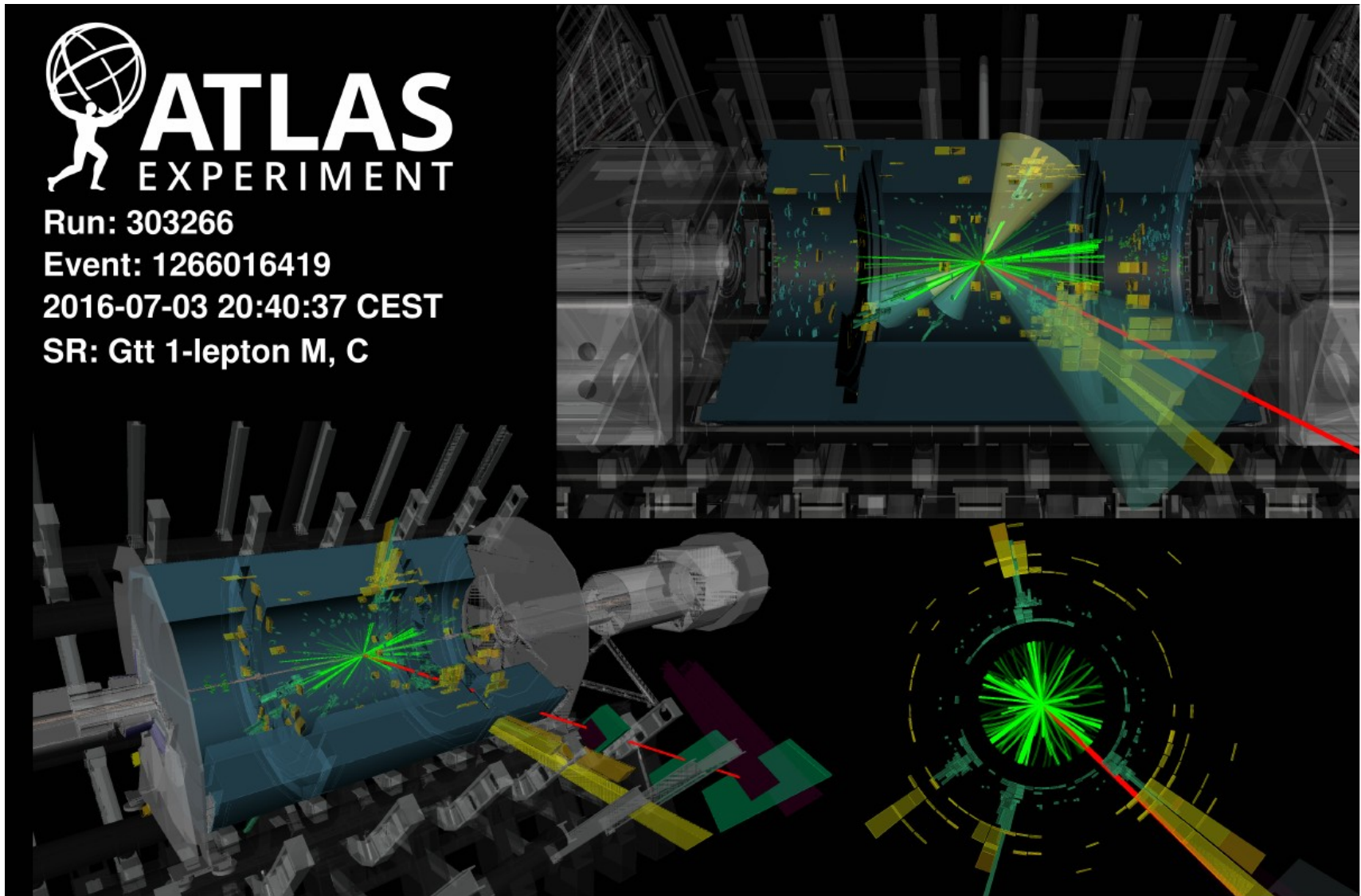
23.10.2019



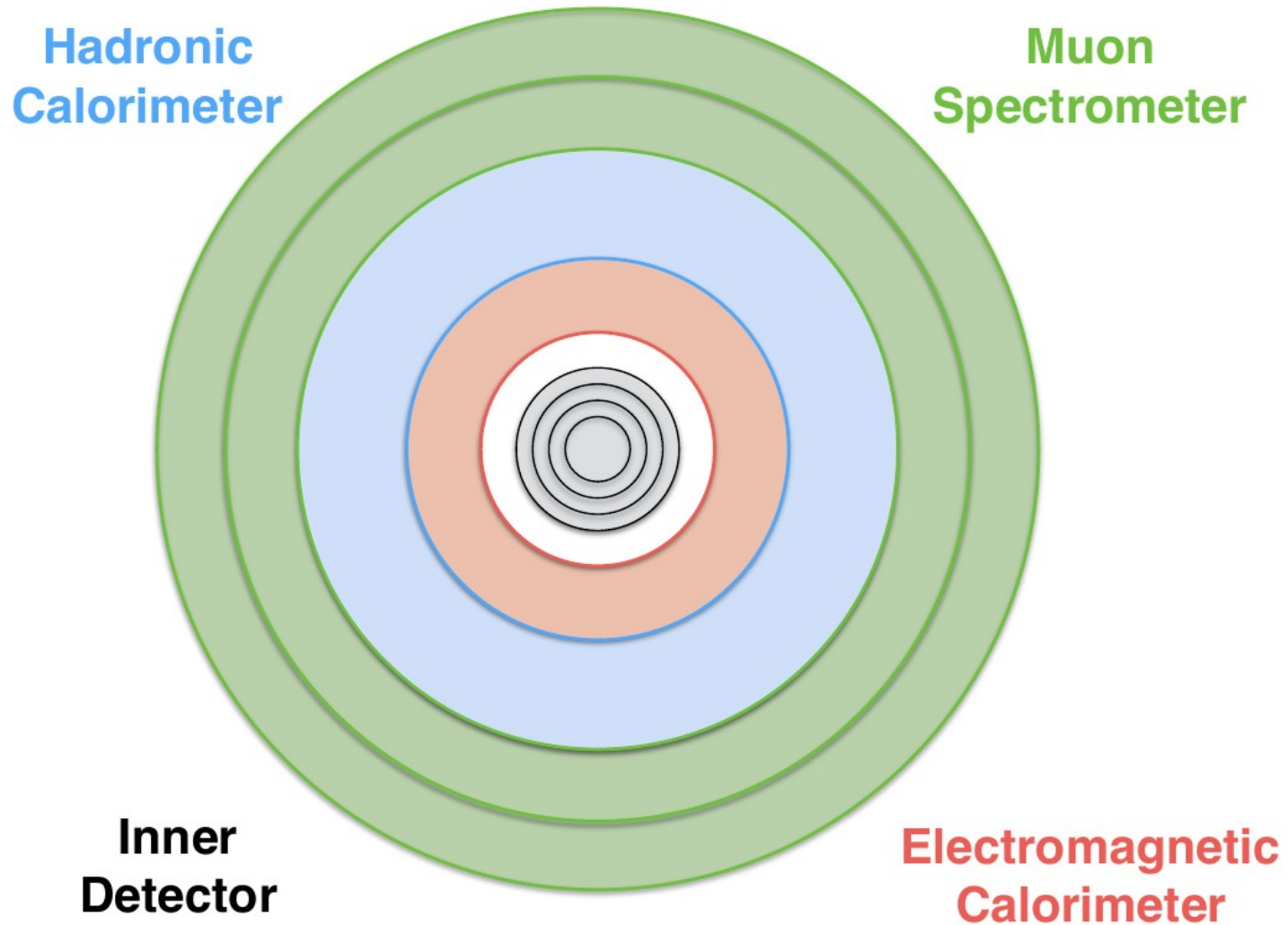
What is wrong here?



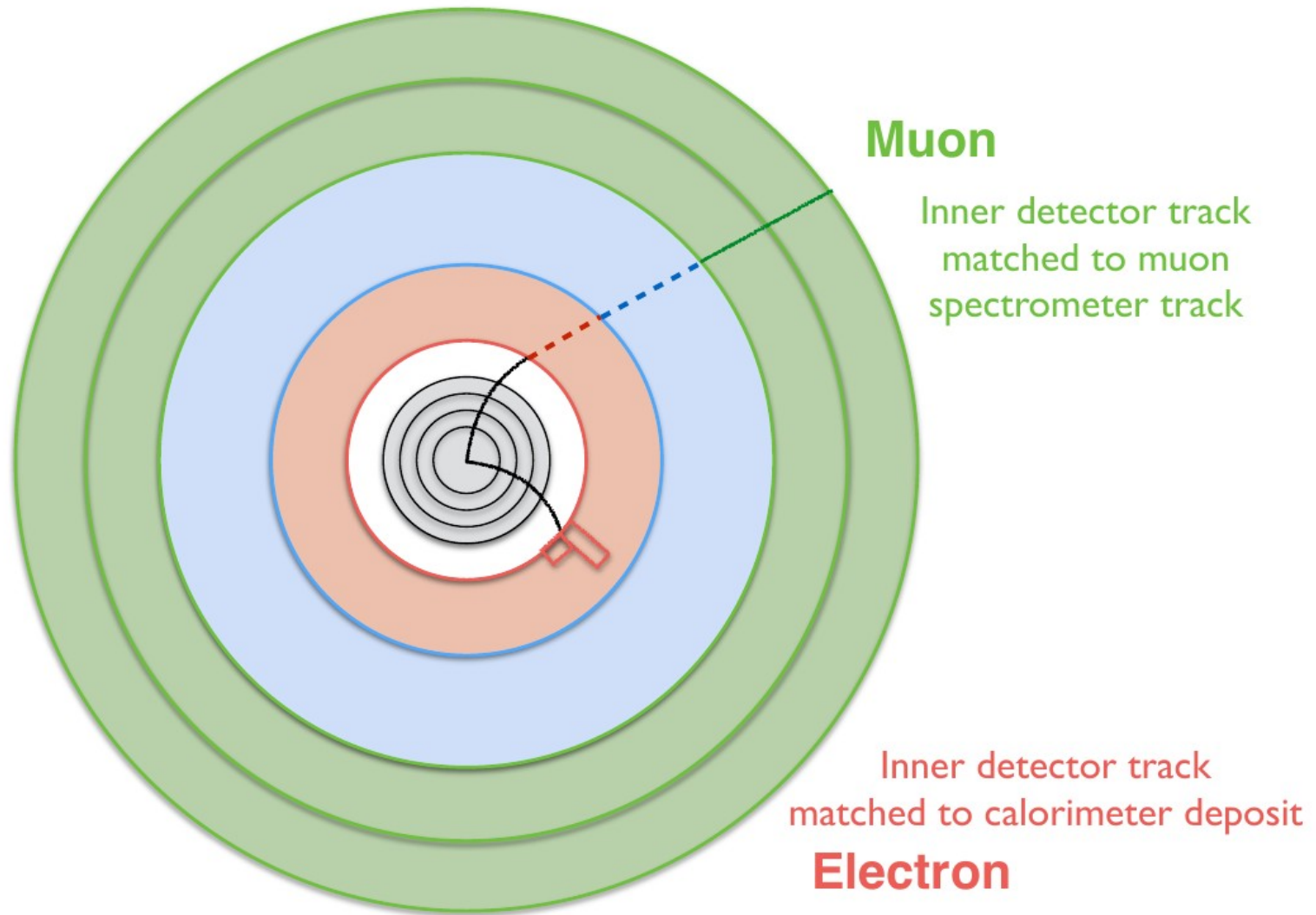
Or here?



What do we see?



What do we see?

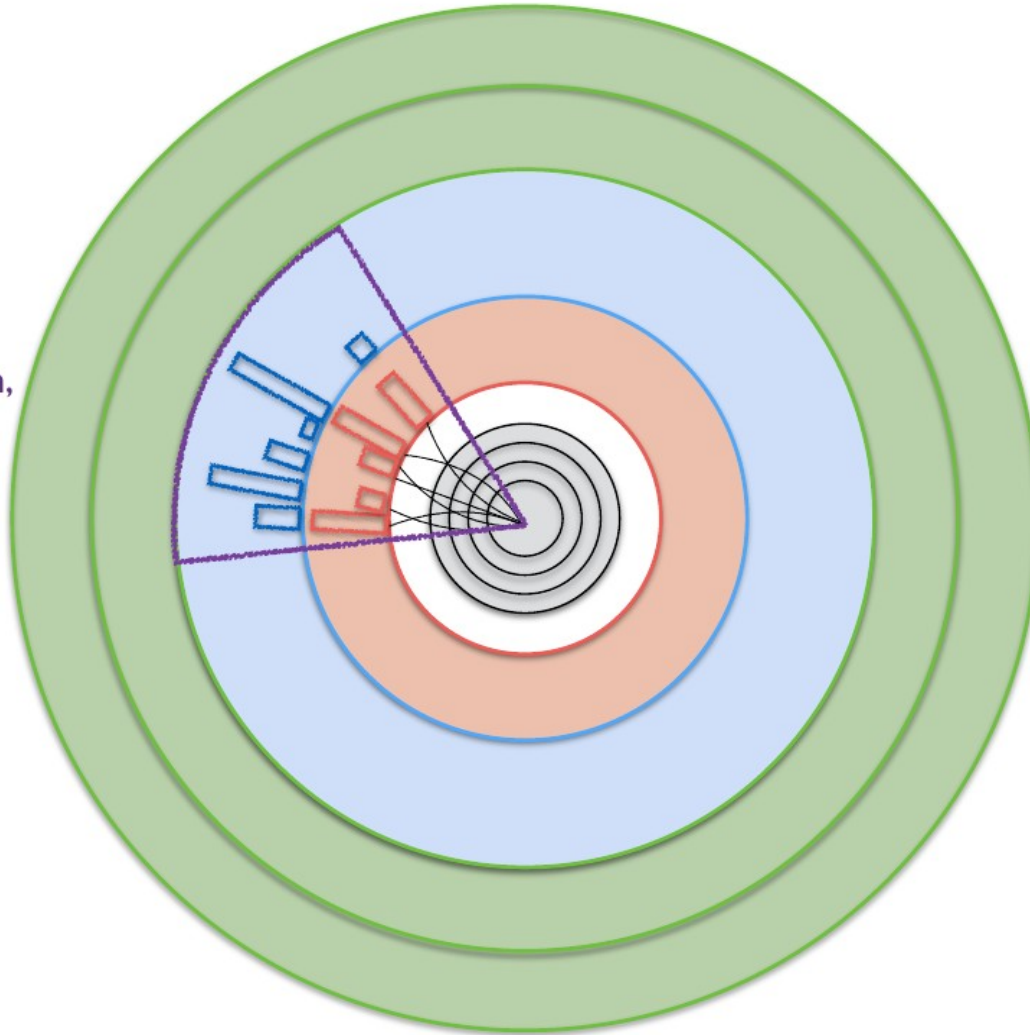


What do we see?

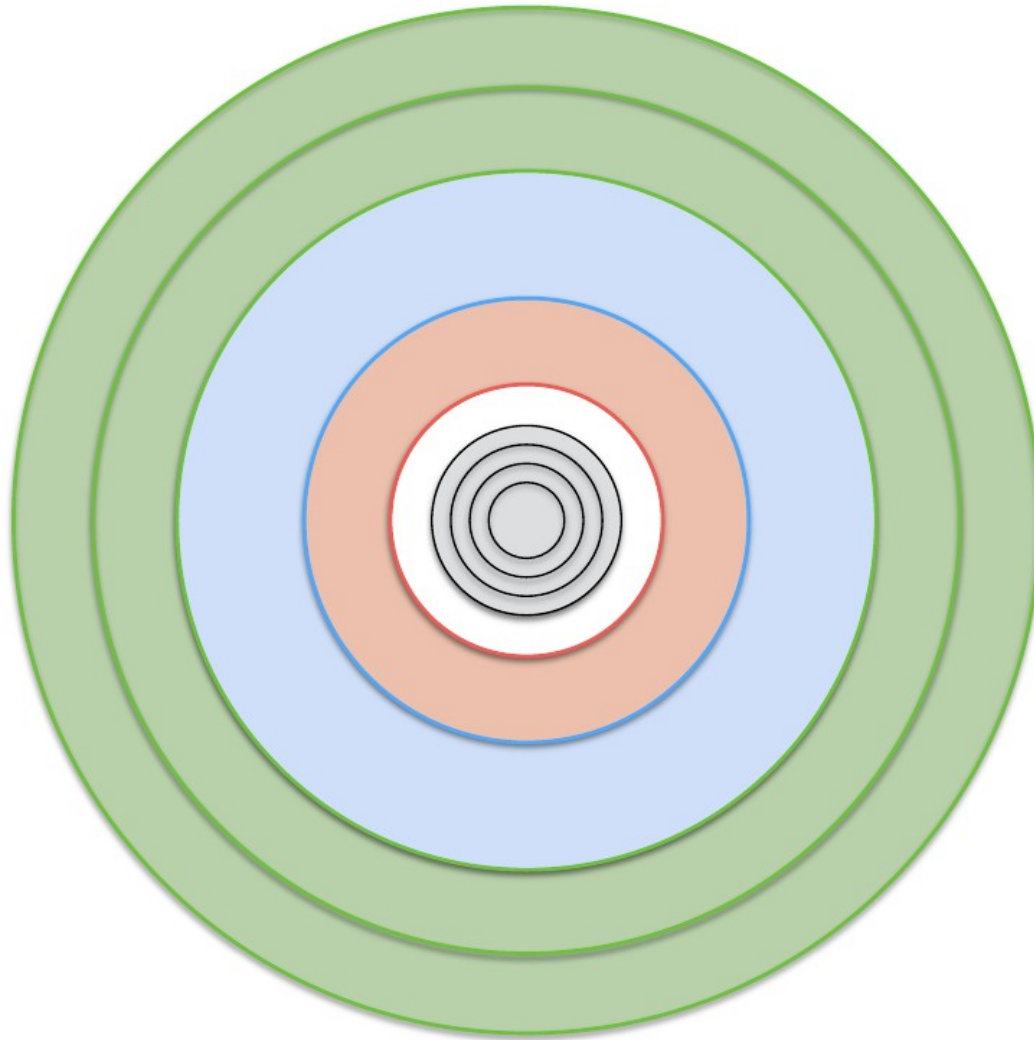


Jet

Spray of particles
initiated by quark or gluon,
measured in calorimeter



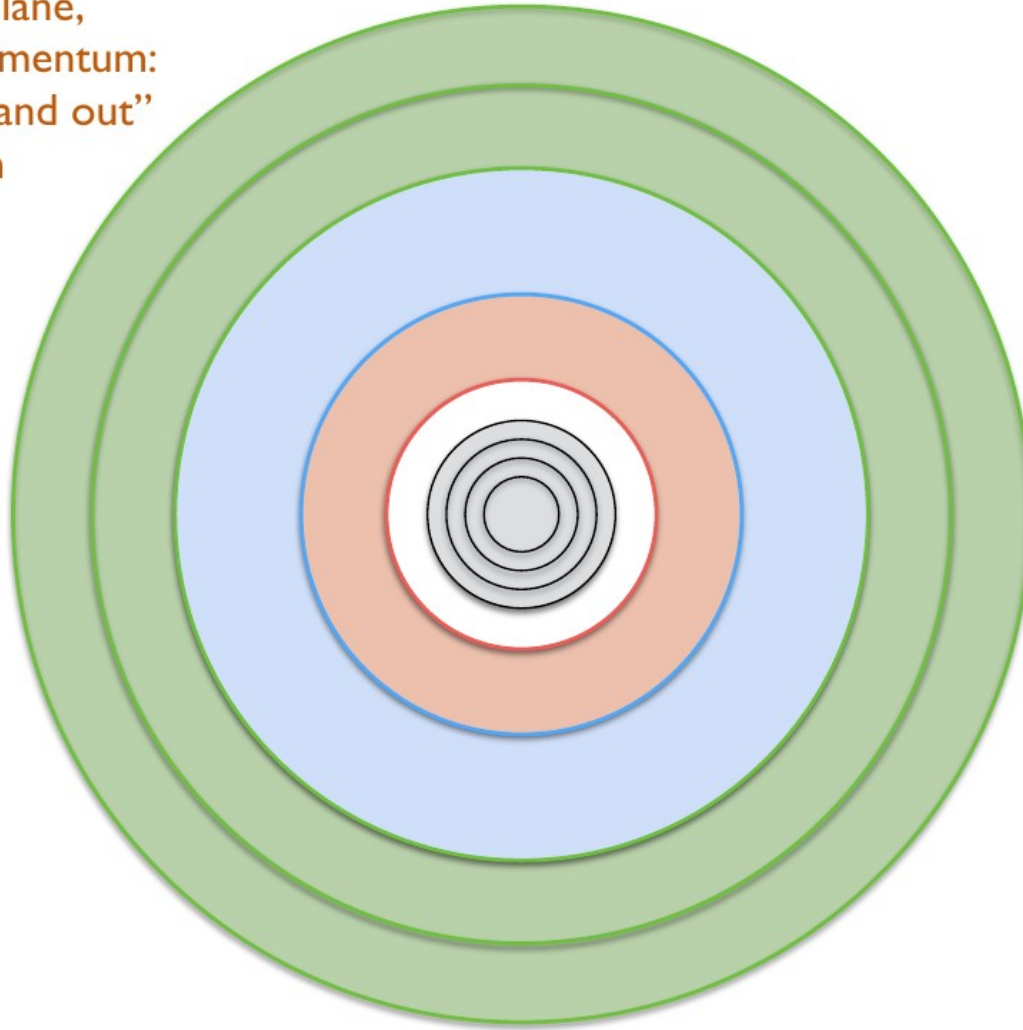
What do we see?



What do we see?



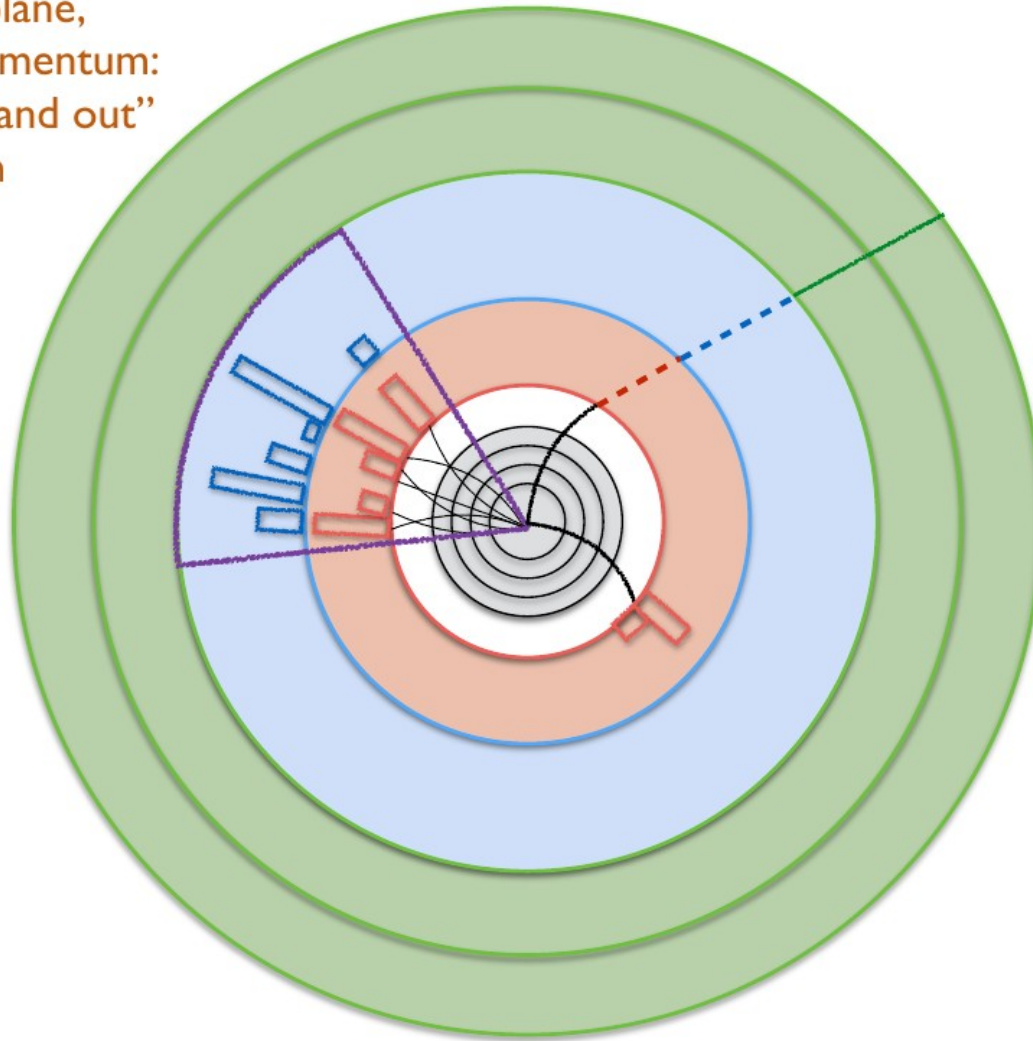
In the transverse plane,
there is no **initial** momentum:
particles are going “in and out”
of this diagram



What do we see?



In the transverse plane,
there is no **initial** momentum:
particles are going “in and out”
of this diagram

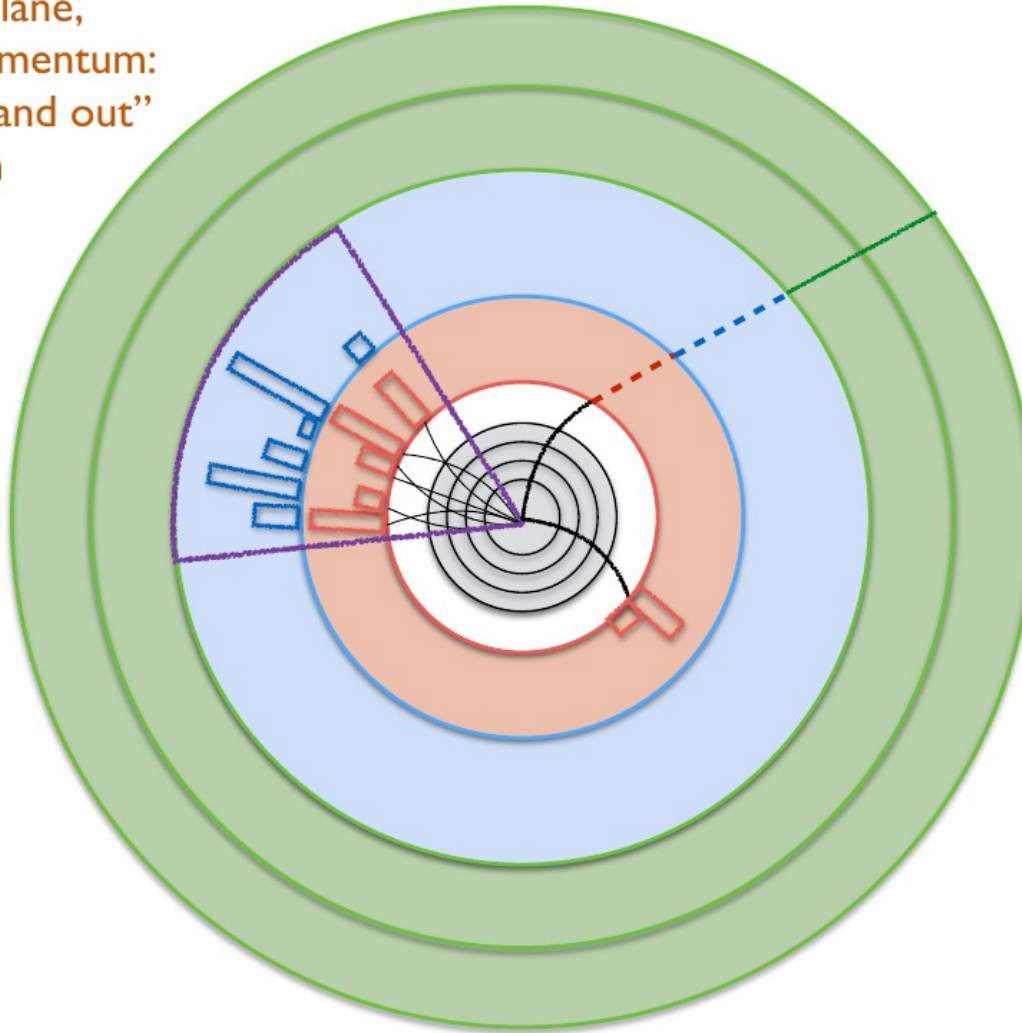


What do we see?



In the transverse plane,
there is no **initial** momentum:
particles are going “in and out”
of this diagram

If you sum up the
final momentum
we measure, that
initial balance
should still hold!



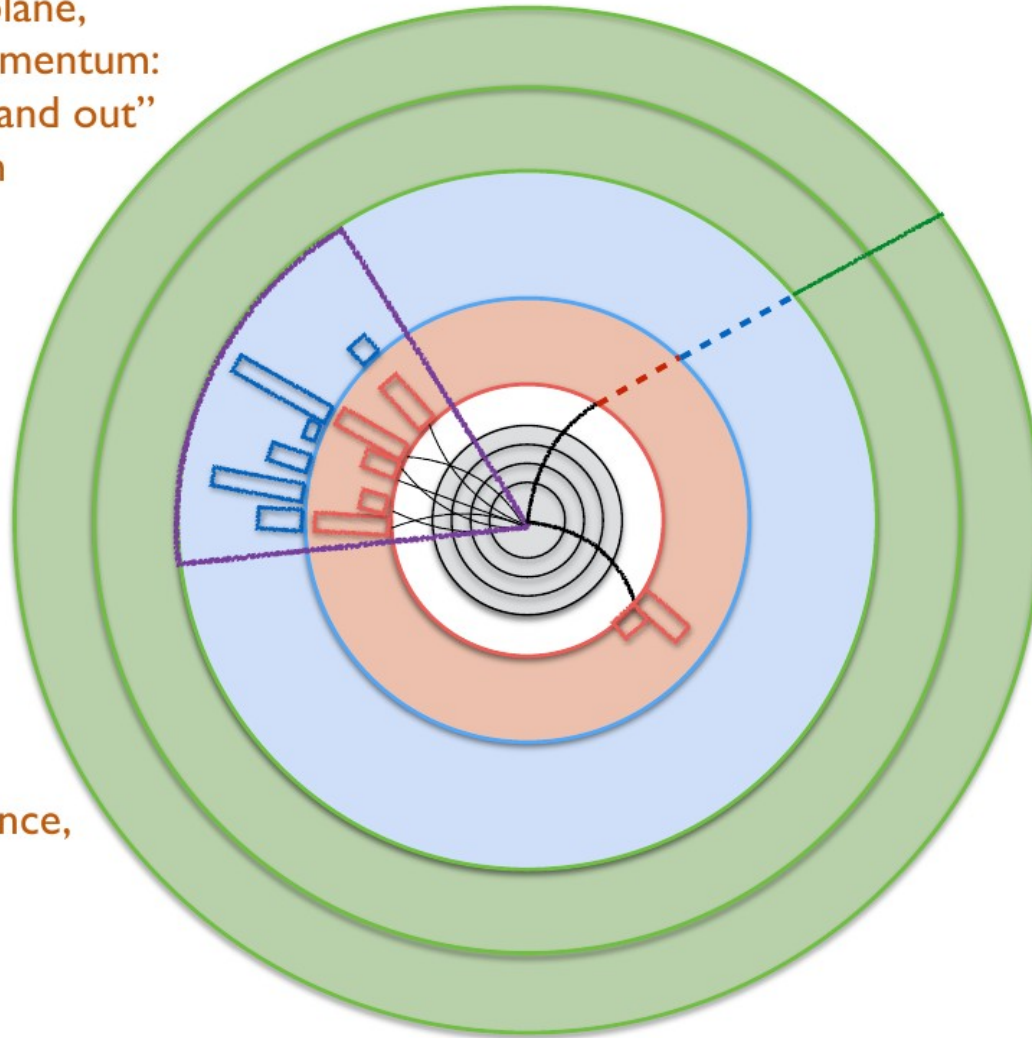
What do we see?



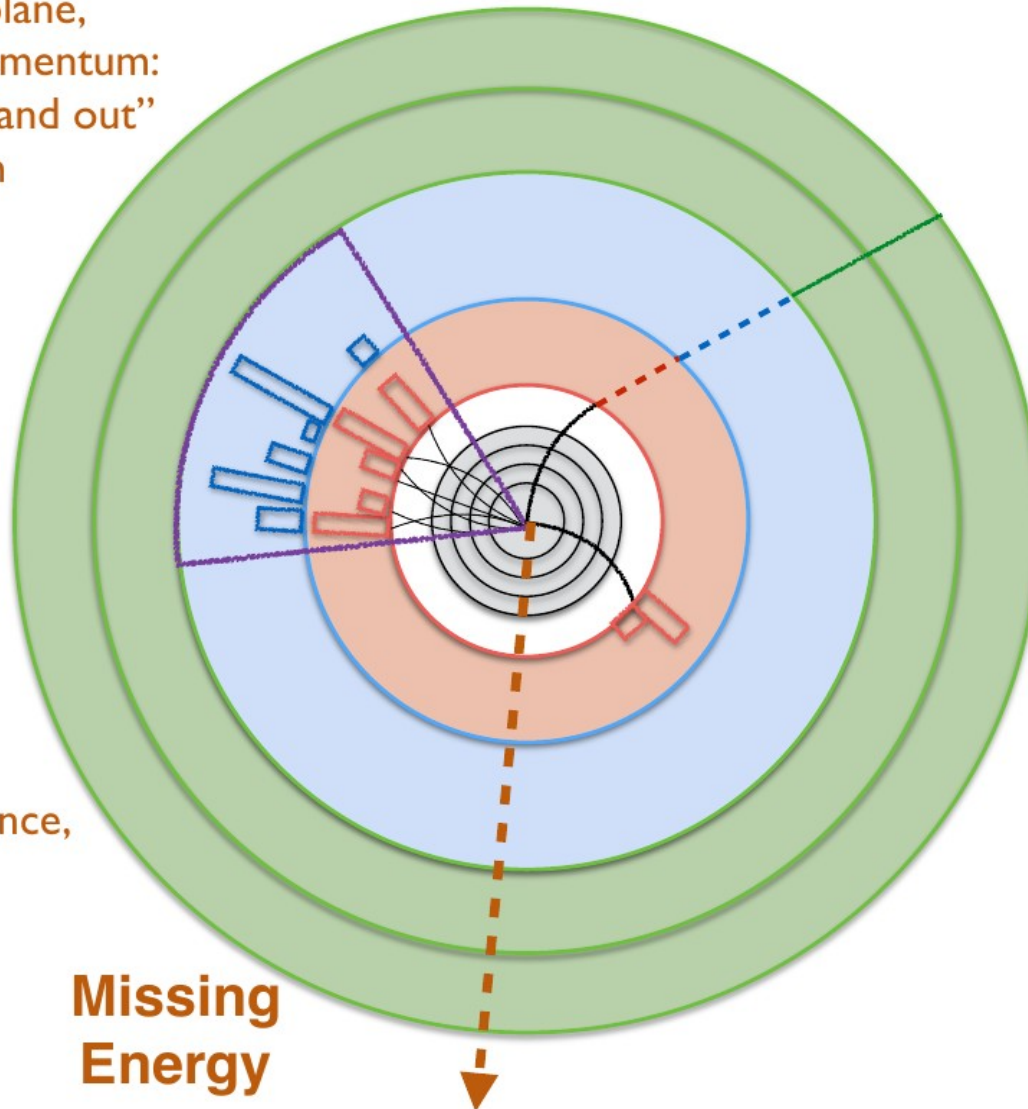
In the transverse plane,
there is no **initial** momentum:
particles are going “in and out”
of this diagram

If you sum up the
final momentum
we measure, that
initial balance
should still hold!

If there is a misbalance,
you have...



If there is a misbalance,
you have...



MET is... what's missing

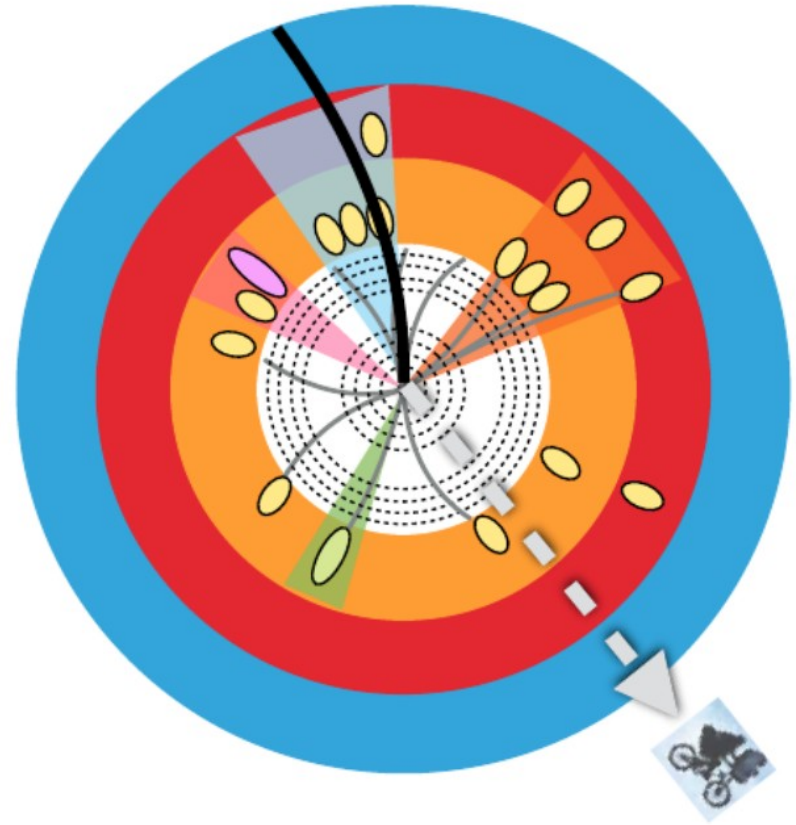


Negative vector sum of:

- Reconstructed particles (e, γ, μ, τ)
→ *Identified and calibrated*
- High- p_T hadronic **jets**
- Soft particle contributions
(**clusters** / tracks)

Sensitive to detector effects

- Smeared out by pileup
- Mismeasurements and defects need to be diagnosed and understood

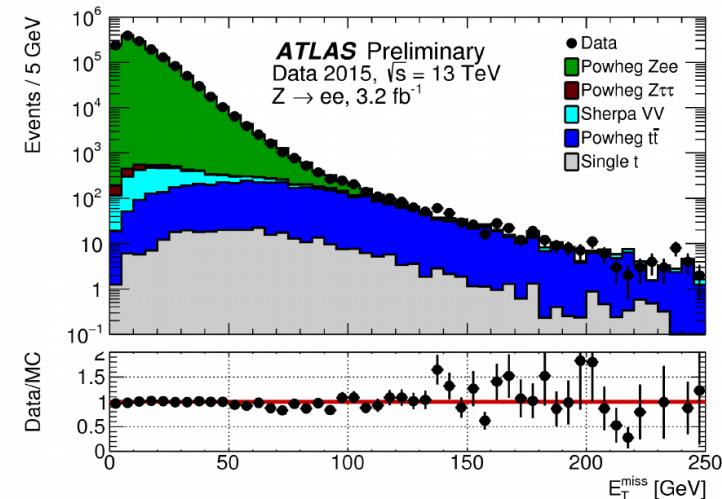
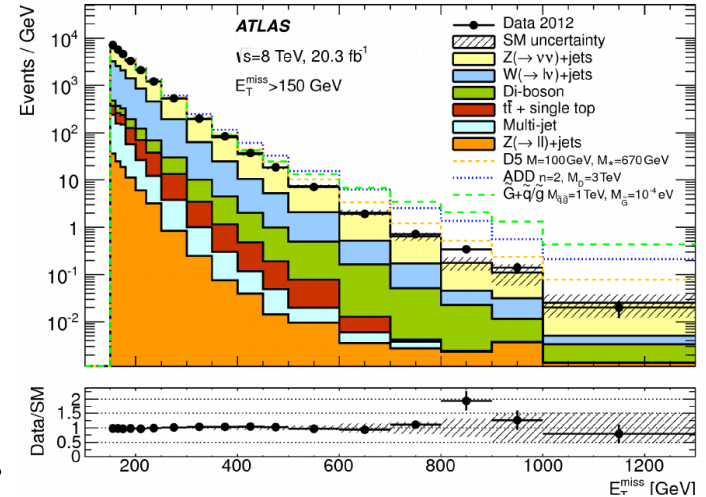
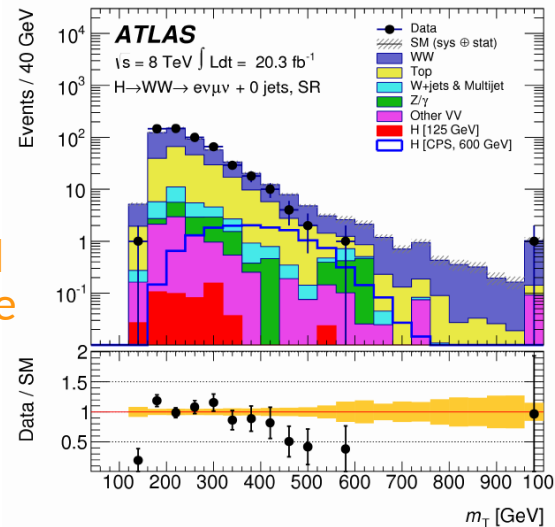


MET is... a guide to (the most?) interesting physics

- Represents total transverse momentum carried by invisible particles: neutrinos, dark matter, SUSY...
- Signals may appear in tails of MET distribution, or in (semi-)resonant structures such as transverse masses.
- SM Backgrounds:

“real” — processes creating neutrinos

“fake” — mismeasured events break transverse momentum balance



MET is... a kinematic quantity



- Really just a two-vector: `mpx` and `mpy`.
 - For diagnostic reasons, also store `sumet`: total pT of all objects used to compute MET
- `xAOD::MissingET` — your main entry point:
 - Provides `mpx()`, `mpy()`, `met()`, `phi()`, `sumet()`
 - Identified by name and source tag [advanced usage]
 - Has arithmetic operators so you can add/subtract/scale etc
 - Lives in `xAOD::MissingETContainer`
- Retrieval: `StoreGate/TStore` holds container
 - Get individual objects by name search (fast hash search)

Code example



```
// Get the container from StoreGate
// Note: This is just an example - this container is not for physics usage.
xAOD::MissingETContainer* metCont(0);
ATH_CHECK( evtStore()->retrieve(metCont,"MET_Reference_AntiKt4EMTopo") );

// Typical term names: "RefEle", "RefJet", "PVSoftTrk", "FinalTrk"...
xAOD::MissingET* met_ele = (*metCont)["RefEle"];
xAOD::MissingET* met_jet = (*metCont)["RefJet"];

// Generally, don't iterate over a MET container, except if you just want to
// dump info.
ATH_MSG_INFO("MET1 magnitude: " << met->met() );
ATH_MSG_INFO("MET2 magnitude: " << met2->met() );
ATH_MSG_INFO("MET1 phi: " << met->phi() );
ATH_MSG_INFO("MET2 phi: " << met2->phi() );

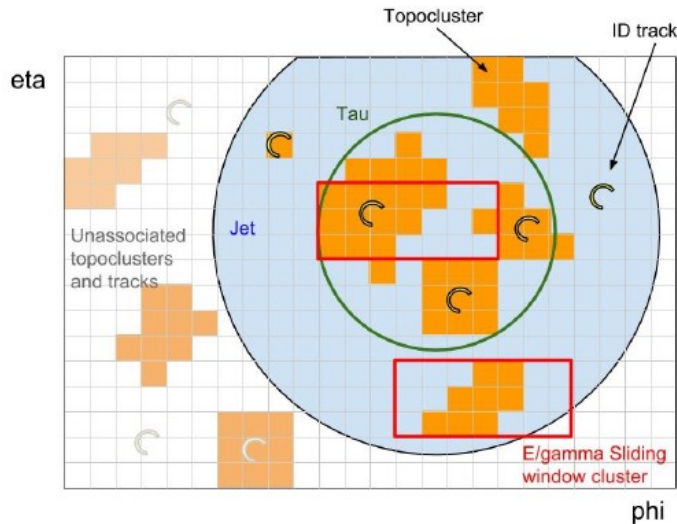
// Algebra (on MET objects, not pointers)
xAOD::MissingET metsum = *met + *met2;
ATH_MSG_INFO("RefEle+RefJet magnitude: " << metsum.met() );
```


MET is... up to you!



- Release 20+ EDM facilitates customisation by analysers:
 - MET group provides **association maps** encoding how to construct the event-level
 - MET and **METMaker** tool to assist this process.
 - Electron/photon/tau/muon selection is entirely **user-specified**
 - Allows **consistency** between analysis event selection and computation of MET quantity (systematic uncertainties etc)
 - “**Harmonised**” definitions agreed upon by physics groups
 - **Jet selection working points** are supplied by Jet/ETmiss, as these affect MET performance and systematics in a non-trivial manner.
 - Objects can be “**marked invisible**” for control regions etc.

MET is... associations

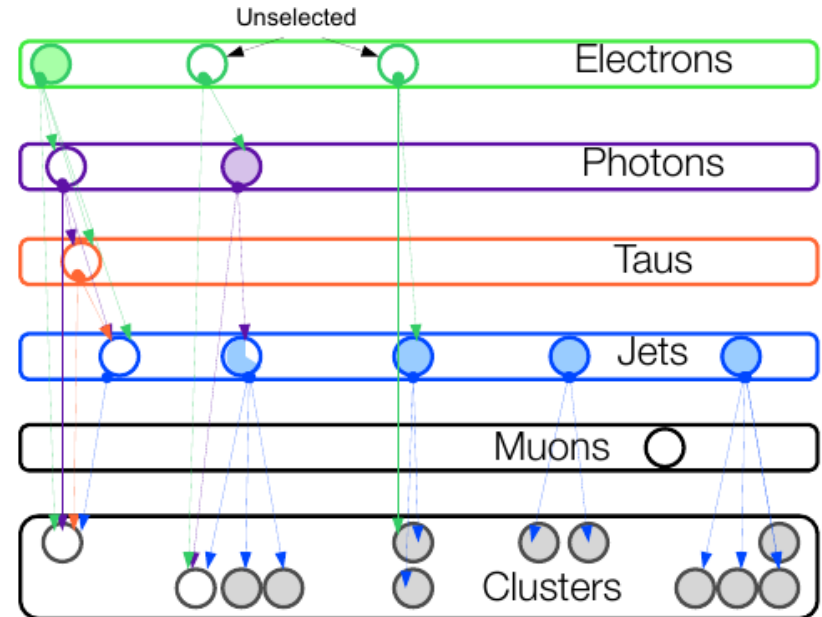


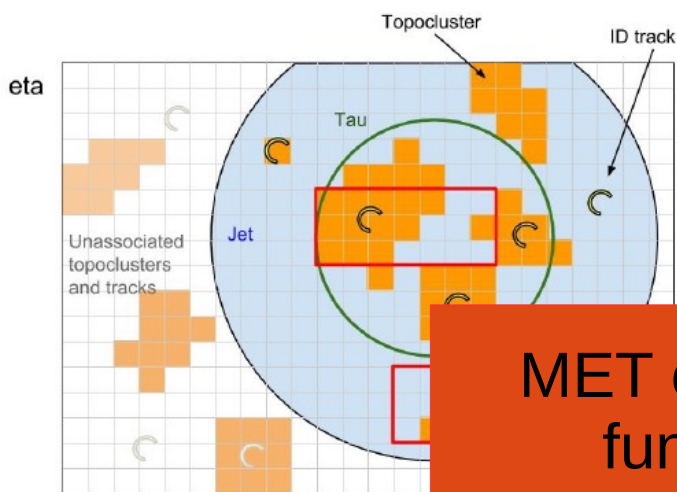
ATLAS object reconstruction domains run independently: a “jet” may be an electron, a photon and/or a tau.

Constituent tracks and clusters may not be identical — some matching procedures needed.

Overlap removal is critical! Cannot blindly sum up all objects otherwise double-counting **will happen**.

Reconstructed objects are complemented with unassociated clusters/tracks for better total momentum balance.



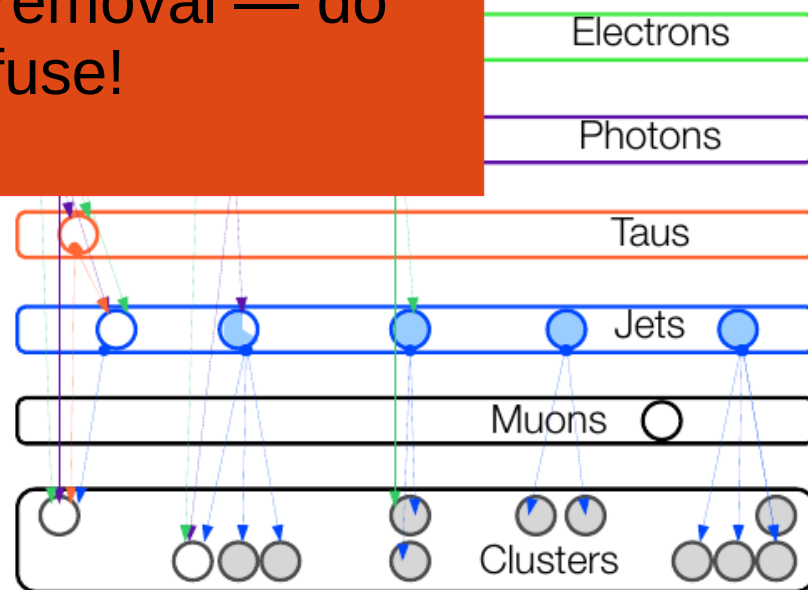


ATLAS object reconstruction domains run independently: a “jet” may be an electron, a photon and/or a tau. Constituent tracks and clusters may be matching

Overlap removal blindly sum up a double-counting will happen.

Reconstructed objects are complemented with unassociated clusters/tracks for better total momentum balance.

MET overlap removal does not function the same way as analysis overlap removal — do not confuse!



Making MET — may be done in your favorite framework



```
// Get the map and core container from StoreGate and reset the object selection flags
const xAOD::MissingETAssociationMap* metMap(0);
const xAOD::MissingETContainer* metCore(0)
ATH_CHECK( evtStore()->retrieve( metMap, "MET_Assoc_AntiKt4EMTopo" ) );
ATH_CHECK( evtStore()->retrieve( metCore, "MET_Core_AntiKt4EMTopo" ) );
metMap-> resetObjSelectionFlags();

// Create your output MET (aux) container
xAOD::MissingETContainer myMetCont;
xAOD::MissingETAuxContainer myMetAuxCont;
myMetCont.setStore( &myMetAuxCont ); // The argument has to be a pointer

// Assuming you have set up an instance of METMaker,
// call rebuildMET on selected objects
ATH_CHECK( metMaker->rebuildMET( "RefEle", // name of MET term to create
                                xAOD::Type::Electron, // type of object
                                &myMetCont, // pointer to container to fill
                                &mySelElectrons, // pointer to object collection
                                metMap ); // pointer to the map

// same for photons, taus, muons, ...
// Now call rebuildJetMET to construct jet and soft terms
ATH_CHECK( metMaker->rebuildJetMET( "RefJet", // name of jet term to create
                                   "PVSoftTrk", // name of soft term to create (this is for TST)
                                   &myMetCont, // pointer to container to fill
                                   &myCalibratedJets, // pointer to input jet collection
                                   metCore, // pointer to core MET container
                                   metMap, // pointer to the map
                                   true ); // do JVT cut (recommended)

// Finally, sum up all the terms in the container to produce the "final" terms
ATH_CHECK( metMaker->buildMETSum( "FinalTrk", // name of total term to create (this is for TST)
                                 &myMetCont ); // pointer to container to fill
```

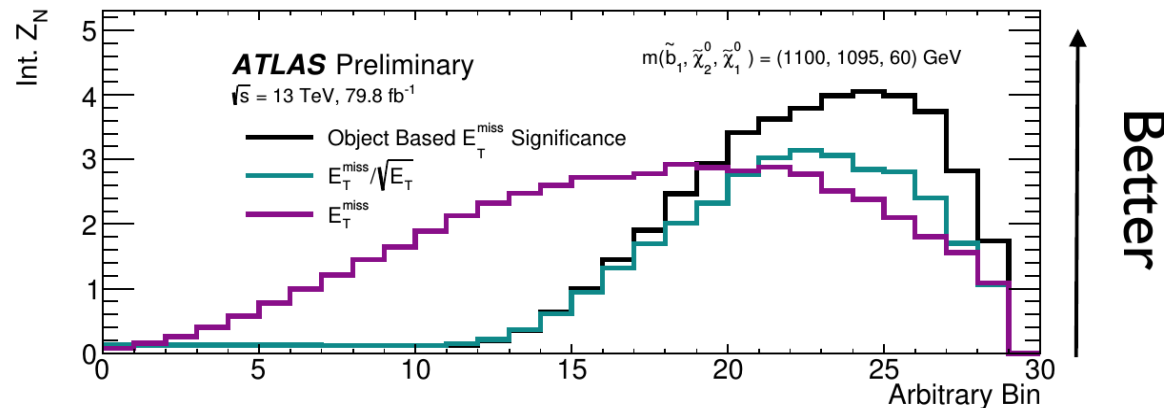
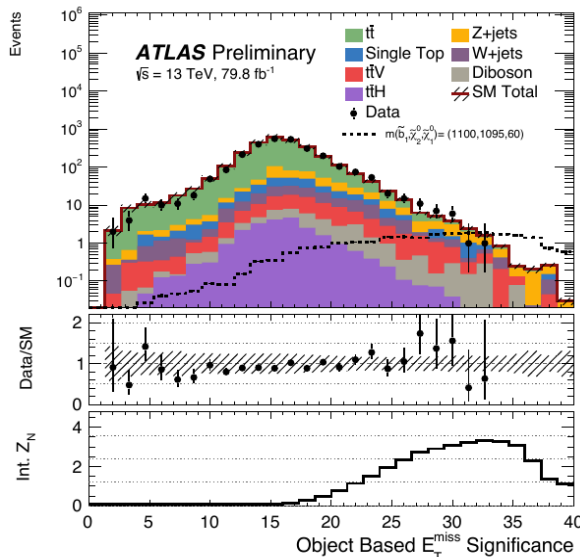
For debugging etc, these
can fill a list of objects
that survived the MET
overlap removal

MET is... significant

Twiki



- Fake MET is often caused by object mismeasurement
- But we measure object resolution: we know what's likely to be mismeasured
- Can use this information to make a new variable: MET Significance, which weights MET by how likely it is to be “real”
- Can make significant improvements to analyses!



Parting points



- MET has to be rebuilt with METMaker as agreed on by your physics group
 - xAOD “Reference” collection has arbitrary object selection and no jet calibration. **Do not use this!**
- Every MET term means something different — iterating over them (e.g. with TTree::Draw or in an event loop) is somewhat meaningless, so know what you’re looking for.
- Pass in only your selected leptons and photons, but **all jets**.
 - → Try the different jet working points! Different performance depending on your final state
- If you work with copied objects (e.g. to calibrate/correct), you must decorate the copy with an ElementLink to the original object, else it will not be found in the MET map.
- It’s not “Missing Energy”!!!

Want to get involved? Contact us – many nice tasks available.



- **MET term:** A single MET object corresponding to the contributions of a specified object type, e.g. electron term, photon term, jet term
- **Hard term:** The term summed from all fully-reconstructed physics objects
- **Soft term:** The term contributed by unassociated clusters/tracks (a.k.a. constituents/signals)
- **TST/CST:** Soft terms built from tracks/clusters, where tracks are always associated to the primary vertex
- **Track MET:** MET constructed with ID tracks replacing calorimeter jet measurements



- [Etmiss subgroup twiki](#) – meetings Monday @ 2pm
- [MET analysis code example](#)
- [METUtilities Twiki page](#)
- [Recommendations for Rel 21](#)
- [Run2xAODMissingET Twiki](#) - description of xAOD content/containers
- [MET Reconstruction tutorial](#)
- Mailing list: atlas-cp-jetetmiss-missinget@cern.ch

Package overview

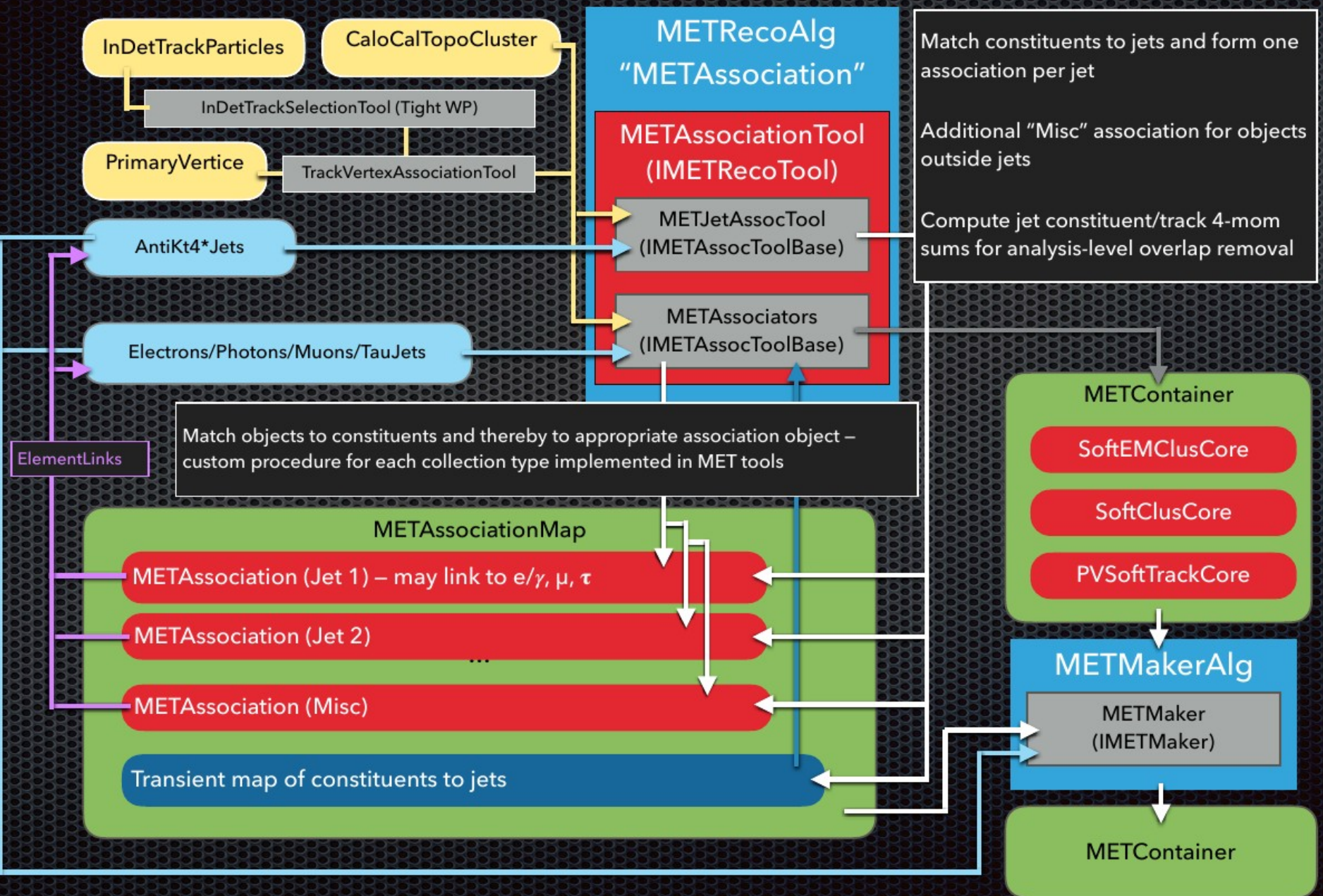


METUtilities package
met::METMaker
met::METSystematicsTool

xAODMissingET package
xAOD::MissingET(Container)

MET Core Soft Term
xAOD::MissingETAssociationMap
METReconstruction
xAOD::MissingETComposition
met::METRebuilder
xAOD::MissingETComponentMap
METPerformance
MET Truth Association Maps

MET Reconstruction data flow



MET Reconstruction data flow

