DIS Electron Finding in ePIC TDR Readiness

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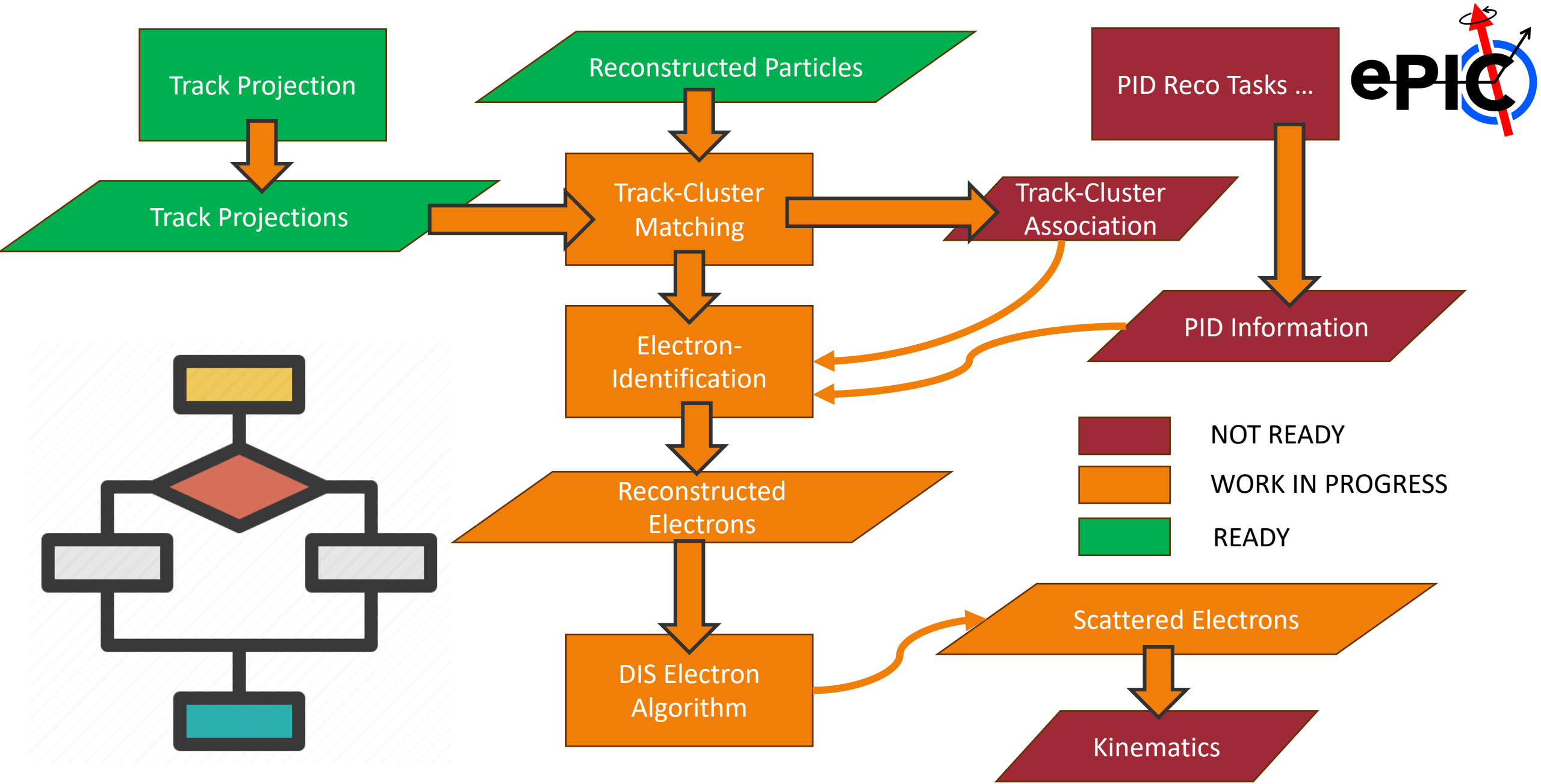
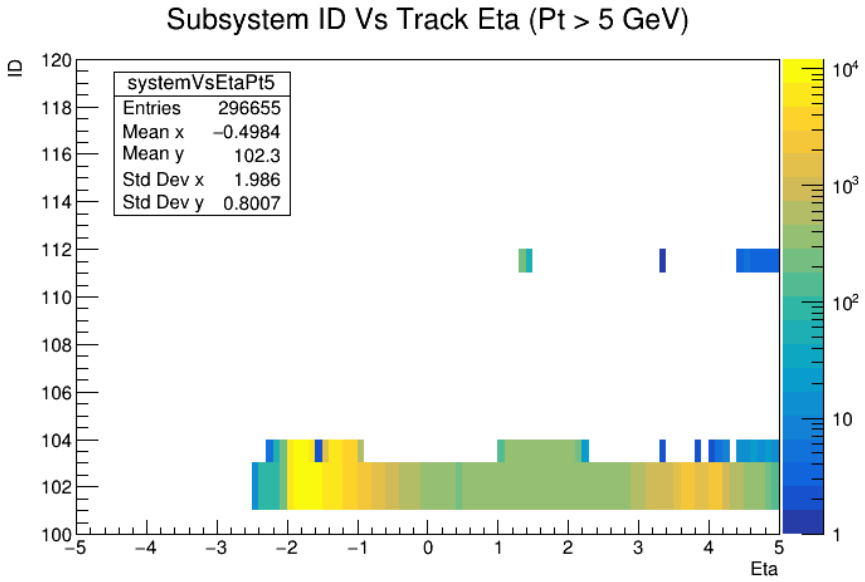
SPECIAL THANKS: Tyler Kutz, Brian Paige, Tristan Protzman, Temple U, Kong Tu, Andrii V, Markus D., Wouter D. Dmitry K. ….


Track Projection
Track Projections
Reconstructed Particles
Track-Cluster Matching
Track-Cluster Association
PID Reco Tasks …
PID Information
Electron-Identification
Reconstructed Electrons
DIS Electron Algorithm
Scattered Electrons
Kinematics
NOT READY
WORK IN PROGRESS
READY

Track Projections - Resolved



Track projections show ID (detector id) at eta values that should not be possible

Thanks to Tyler K., Brian P. and OSU students for working on this.

Thanks to software experts for help

- TrackPropagation_factory: resolve an indexing bug by using ACTS surface ID fields #1257
- Fixed and merged into eicrecon
- Brian confirmed it looks good except that there is a typo mixing up endcap CALOs
- PR hotfix in prep

Track Cluster Matching

- Initial Track-Cluster Matching algorithm in development
- **Association between Reco Cluster and ReconstructedParticle #52**

Blocking Issue:
- Tracks are not filled
- Skip directly to Reconstructed Particles
- No relationship for associating projection<->track<->reconstructed particle

Solution:
Tracks as first-class citizen

Update to data-model

```
+
+   edm4eic::TrackClusterMatch:
+     Description: "Association between a Cluster and a ReconstructedParticle"
+     Author : "D. Brandenburg"
+     Members:
+       - uint32_t          cluID             // Index of corresponding cluster (position in cluster array)
+       - uint32_t          plcID             // Index of corresponding ReconstructedParticle (position in reco particle array)
+       - float             weight            // weight of this association
+     OneToOneRelations:
+       - edm4eic::Cluster  clu               // reference to the cluster
+       - edm4eic::ReconstructedParticle plc            // reference to the Reco particle
```

DIS Lepton Finder Algorithms

- So far two variants:
- **Algorithms and factories for scattered electrons #1277**

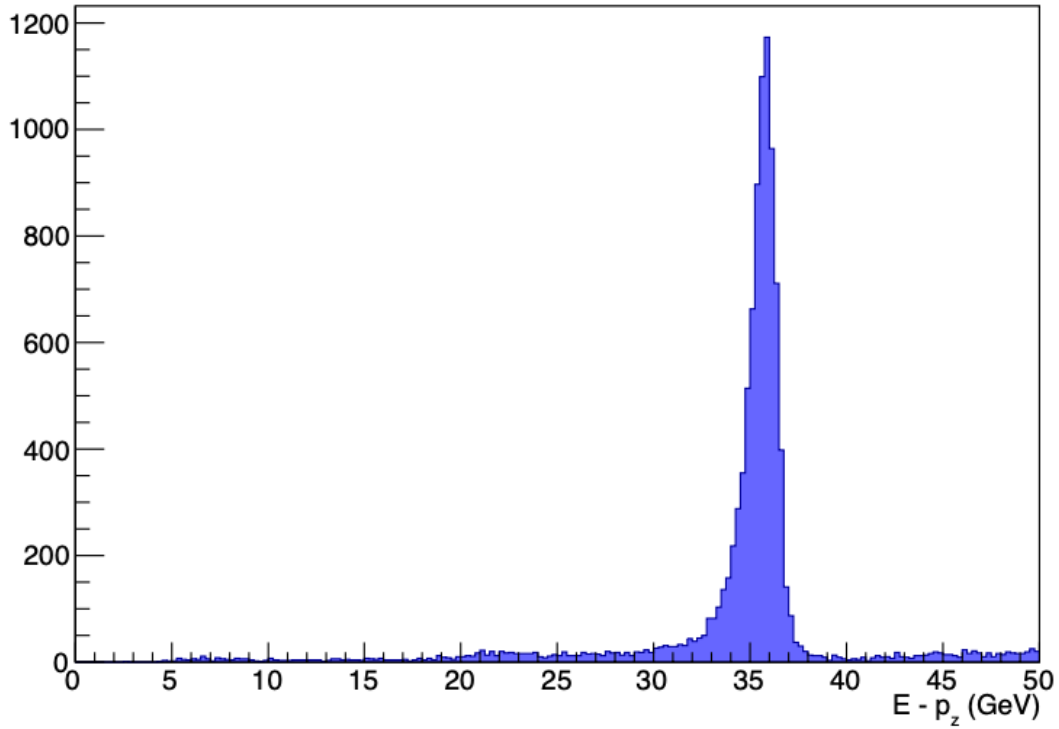
- `ScatteredElectronsTruth` – finds MC scattered Electron and get associated reconstructed particle – collection of length 1, always the true* electron

- `ScatteredElectronsEMinusPz` – computes E-Pz for electron candidates and corresponding hadronic final state

- *seems there is some issue in Pythia with the identification of the scattered electron from MC info…

E-Pz algorithm

- Track matching next milestone for fully reconstruction-based E/p cut
- Further ePID refinement with addition of $E - p_z$ cut (thanks to K. Tu for help on implementation)
- Implementation of EICrecon algorithm/ factory underway
- Still considering best output format, how to handle multiple DIS electron candidates, etc.



Thank you to Kong Tu and Tyler Kutz

ScatteredElectronsTruth

```
inline auto find_first_scattered_electron(const edm4hep::MCParticleCollection* mcparts) {
  return find_first_with_status_pdg(mcparts, {1}, {11});
}
```

```
template<class T>
auto find_first_with_status_pdg(
    const T* parts,
    const std::set<int32_t>& status,
    const std::set<int32_t>& pdg) {
  T c;
  c.setSubsetCollection();
  for (const auto& p: *parts) {
    if (status.count(p.getGeneratorStatus()) > 0 &&
        pdg.count(p.getPDG()) > 0) {
      c.push_back(p);
      break;
    }
  }
  return c;
}
```

ScatteredElectronsTruth

```cpp
// Get first scattered electron
const auto ef_coll = find_first_scattered_electron(mcparts);
if (ef_coll.size() == 0) {
  m_log->trace("No truth scattered electron found");
  return;
}

// Associate first scattered electron
// with reconstructed electron
auto ef_assoc = rcassoc->begin();
for (; ef_assoc != rcassoc->end(); ++ef_assoc) {
  if (ef_assoc->getSimID() == (unsigned) ef_coll[0].getObjectID().index) {
    break;
  }
}
```

ScatteredElectronsEMinusPz

```
for (const auto& p: *rcparts) {
  // this is a hack - getObjectID() only works within
  // a collections, not unique across all collections.
  // What we want is to add all reconstructed particles
  // except the one we are currently considering as the
  // (scattered) electron candidate.
  // This does work though and in general it has only
  // one match as I would hope (tested on pythia events)
  if ( edm4hep::utils::magnitude(p.getMomentum())
    != edm4hep::utils::magnitude(e.getMomentum()) ) {
    vHadron.SetCoordinates(
        p.getMomentum().x,
        p.getMomentum().y,
        p.getMomentum().z,
        m_pion // Assume pion for hadronic state
      );

    // Sum hadronic final state
    vHadronicFinalState += vHadron;
  } else {
    m_log->trace( "Skipping electron in hadronic final state" );
  }
```

Issue: getObjectID() only works within same collection

Solution: use Subset Collection (PR in progress)

ScatteredElectronsEMinusPz

```
// Calculate the E-Pz for this electron
// + hadron final state combination
// For now we keep all electron
// candidates but we will rank them by their E-Pz
double EPz=(vScatteredElectron+vHadronicFinalState).E()
          - (vScatteredElectron+vHadronicFinalState).Pz();
```

Compute E-Pz for all (negative charge) electron candidates identified in ReconstructedElectron collection

ScatteredElectronsEMinusPz

```
// map sorts in ascending order by default
// sort by descending
bool first = true;
// for (auto kv : scatteredElectronsMap) {
for (auto kv = scatteredElectronsMap.rbegin(); kv != scatteredElectronsMap.rend(); ++kv) {

  double EMinusPz = kv->first;
  // Do not save electron candidates that
  // are not within range
  if ( EMinusPz > m_cfg.maxEMinusPz
    || EMinusPz < m_cfg.minEMinusPz ){
    continue;
  }
```

Returns ‘ScatteredElectronsEMinusPz` collection – ranked with the highest E-Pz first, then in descending order

Even without strict electron PID – right “most” of the time

Checking the Scattered Electron

- Independent use of ScatteredElectronsTruth_factory and ScatteredElectronsEMinusPz_factory allows us to ‘check’ the algorithm’s performance

```
[reco:ScatteredElectronsEMinusPz] [trace] We have 3 candidate electrons
[reco:ScatteredElectronsEMinusPz] [trace] Skipping electron in hadronic final state
[reco:ScatteredElectronsEMinusPz] [trace]       E-Pz=17.044048885959747
[reco:ScatteredElectronsEMinusPz] [trace]       ScatteredElectron has Pxyz=( 1.0658381, 2.5452766, -8.107633 )
[reco:ScatteredElectronsEMinusPz] [trace] skipping positron
[reco:ScatteredElectronsEMinusPz] [trace] skipping positron
[reco:ScatteredElectronsEMinusPz] [trace] Selecting candidates with 0 < E-Pz < 10000000
[reco:ScatteredElectronsEMinusPz] [trace] Max E-Pz Candidate:
[reco:ScatteredElectronsEMinusPz] [trace]       E-Pz=17.044048885959747
[reco:ScatteredElectronsEMinusPz] [trace]       ScatteredElectron has Pxyz=( 1.0658381, 2.5452766, -8.107633 )
[reco:ScatteredElectronsTruth] [trace] We found 1 scattered electrons using Truth assocaition
[reco:ScatteredElectronsTruth] [trace] TRUTH scattered electron has E-Pz = 17.044048885959747
[reco:ScatteredElectronsTruth] [trace] TRUTH scattered electron has Pxyz=( 1.065838098526001, 2.545276641845703, -8.107632637023926 )
 and E/p = 1.0000000507582056
```

These allow ‘baseline’ algorithms to compare against as we develop more sophisticated (ML) algorithms

Summary

- Next Major Milestones
  - Proper use of `Tracks` - how can eFinder group help? (I have a potential post-doc who would like to help)
  - Fully integrate Track-Cluster Matching
  - Incorporate PID information
  - Setup for advanced lepton finder algorithms
  - Data format updates needed
    - Track-Cluster Match
    - Generic ScatteredElectron cases (see next slides)
    - Kinematics (inclusive, semi-inclusive, exclusive, etc.)

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Data format updates

- Track-Cluster Match
- Collection for ranked scattered electrons
  - Something like an object + a likelihood
  - Would be nice to also somehow associate an “algorithm data” object, e.g. E-Pz info for the ScatteredElectronsEMinusPz
- Kinematics formats for:
  - Inclusive
  - Exclusive
  - Etc.

Proposal

- Instead of having ScatteredElectrons (of type ReconstructedParticleCollection)
- Instead, new structure (simplest case):
- ScatteredElectronHypothesis:
  - EMinusPz
  - RankEMinusP
  - isTruthScatteredElectron
  - EOverP
  - HasLeadingCluster
  - …
  - OneToOne Relation
    - recoParticle (points to the electron candidate)
  - OneToOne relation:
    - InclusiveKinematics
    - SemiInclusiveKinematics
    - ExclusiveKinematics
    - …
- Also OneToMany relation on ReconstructedParticle (like PID)

Proposal (more general)

- ScatteredElectronHypothesis:
  - Algorithm Identifier
  - Ranking – single value which tells end user the relative RANK according to this algorithm
  - DATA member based on algorithm
  - OneToOne Relation
    - recoParticle (points to the electron candidate)
  - OneToOne relation:
    - InclusiveKinematics
    - SemiInclusiveKinematics
    - ExclusiveKinematics
    - …
- ScatteredElectronHypothesis can then be a single collection (for all algorithms) or new collections can be added for new algorithms (using the same type)

Electron Finder 07-10-2023

- Progress in June (for July Sim Campaign)
  - PR #666: Provides association containers + truth associations
    merged into main on June 24
  - PR #751: Implement basic electron finding with truth cluster matching
  - Work in parallel with the RECO approach (see tasks below)
- Major Tasks (July):
  - Utilize the July sim campaign output:
    - Implement a processor to test DIS lepton finder
    - Check purity of selected electrons
  - Track Projection Factory: provide track projections at relevant detectors (Tyler Kutz)
    - ✓ Needed data structure identified
    - ✓ Prototype factory in progress
  - Track Match Factory: Matching of projecting tracks to clusters (volunteer?)
    - Nicholas Schmidt already has some code (processor) to study track matching
    - Provides a starting point for factory
  - Study of E/p cuts to implement (volunteer potentially identified, discussing next steps)
  - Study HCAL info for hadron rejection / electron id
- Plans for July sim campaign
  - Utilize “ReconstructedElectrons” to test-drive DIS lepton finder (should be in EICRecon for Aug)
  - Continue work towards towards fully RECO level (complete track matching / compare to truth level matching)

Truth approach

- PR #751 Add reconstructed electron factory, algorithm utilizing E/p cut
  - https://github.com/eic/EICrecon/pull/751
  - ReconstructedElectrons Factory
  - Input:

```
75          {"MCParticles", "ReconstructedChargedParticles", "ReconstructedChargedParticleAssociations",
76          "EcalBarrelScFiClusterAssociations",
77          "EcalEndcapNClusterAssociations",
78          "EcalEndcapPClusterAssociations",
79          "EcalEndcapPInsertClusterAssociations",
80          "EcalLumiSpecClusterAssociations",
81          },
```

  - Output: “ReconstructedElectrons”
- Utilizes the ElectronReconstruction Algorithm
  - Any track with an ECAL match
  - Accept if 0.9 < E/p < 1.2 (needs to be studied and optimized)
  - TODO: use HCAL
  - TODO: handle multiple matches
- This is meant to be initial skeleton – keep same structure for RECO approach