Track-Particle Matching Considerations

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Introduction

❑ While studying track resolutions and efficiencies, I noticed that some fraction of reconstructed tracks did not have an associated particle in the ReconstructedChargedParticlesAssociation branch – why?

❑ After some conversation, learned that the algorithm which matches reconstructed tracks with particles (and fills R.C.P.Associations branch) includes an explicit requirement that the track/particle relative momentum be within 10%

❑ Issue #450 was opened to address this: https://github.com/eic/EICrecon/issues/450

❑ Proposal is to effectively remove this relative momentum criteria from the conditions for track-particle matching and make the association purely geometric (set the momentum difference so high as to be negated)

❑ Following slides are a very quick summary study using reconstructed Pythia-6 files (22.11.3, brycecanyon, 18x275, 1 < Q2 < 10)

❑ Also document the presence of 'duplicate tracks' – two reconstructed tracks with nearly identical momenta

Track-Particle Matching Algorithms

```
const auto p_mag = std::hypot(p.x, p.y, p.z);
const auto p_phi = std::atan2(p.y, p.x);
const auto p_eta = std::atanh(p.z / p_mag);
const double dp_rel = std::abs((edm4eic::magnitude(mom) - p_mag) / p_mag);
// check the tolerance for sin(dphi/2) to avoid the hemisphere problem and allow
// for phi rollovers
const double dsphi = std::abs(sin(0.5 * (edm4eic::angleAzimuthal(mom) - p_phi)));
const double deta = std::abs((edm4eic::eta(mom) - p_eta));


bool is_matching = dp_rel < m_cfg.momentumRelativeTolerance &&
            deta < m_cfg.etaTolerance &&
            dsphi < sinPhiOver2Tolerance;


m_log->trace("    Decision: {}  dp: {:.4f} < {}  &&  d_eta: {:.6f} < {}  && d_sin_phi: {:.4e} < {:.4e} ",
        is_matching? "Matching":"Ignoring",
        dp_rel, m_cfg.momentumRelativeTolerance,
        deta, m_cfg.etaTolerance,
        dsphi, sinPhiOver2Tolerance);


if (is_matching) {
   const double delta =
        std::hypot(dp_rel / m_cfg.momentumRelativeTolerance, deta / m_cfg.etaTolerance,
               dsphi / sinPhiOver2Tolerance);
   if (delta < best_delta) {
      best_match = ip;
      best_delta = delta;
      m_log->trace("    Is the best match now");
   }
```

❑ Default track-particle matching algorithm for ReconstructedChargedParticlesAssociation branch found in: https://github.com/eic/EICrecon/blob/main/src/algorithms/tracking/ParticlesWithTruthPID.cpp

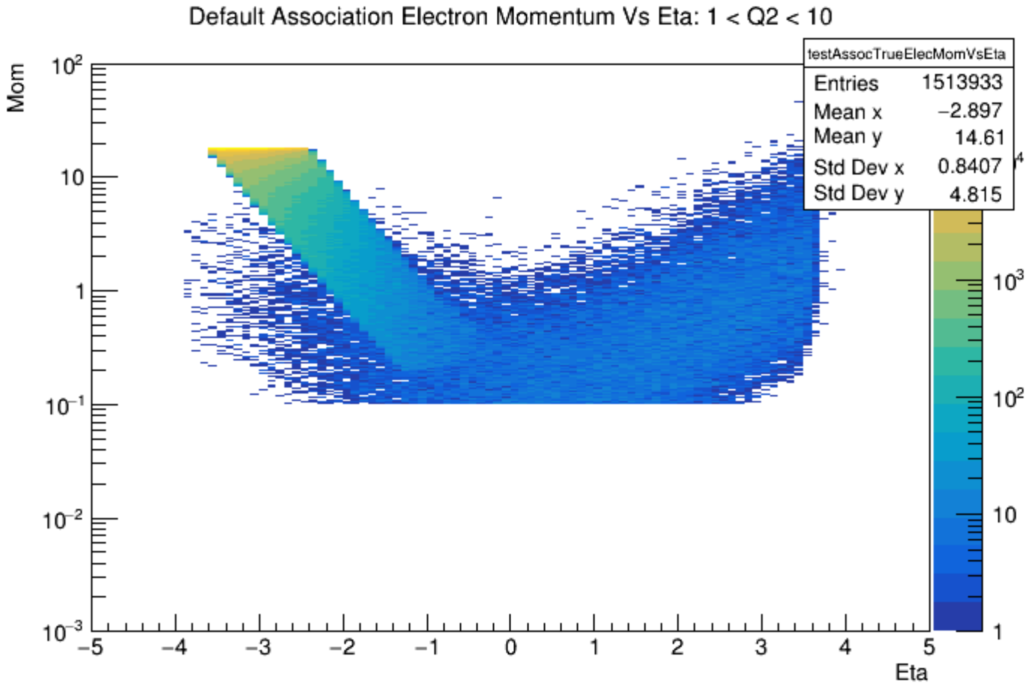
❑ For each track, loop through all particles within certain deta, dephi, and relative dp (0.2, sin(0.5*0.03), and 0.10) – match is particle with closest dR = hypot(dp, deta, dphi)

❑ Issue: Relative momentum difference is used in matching criteria – tracks with a poorly reconstructed momentum (>10%) will not be paired with their particle, even if geo match is close. Poor momentum resolution instead registers as an inefficiency

❑ Look at removing momentum difference as a matching criteria

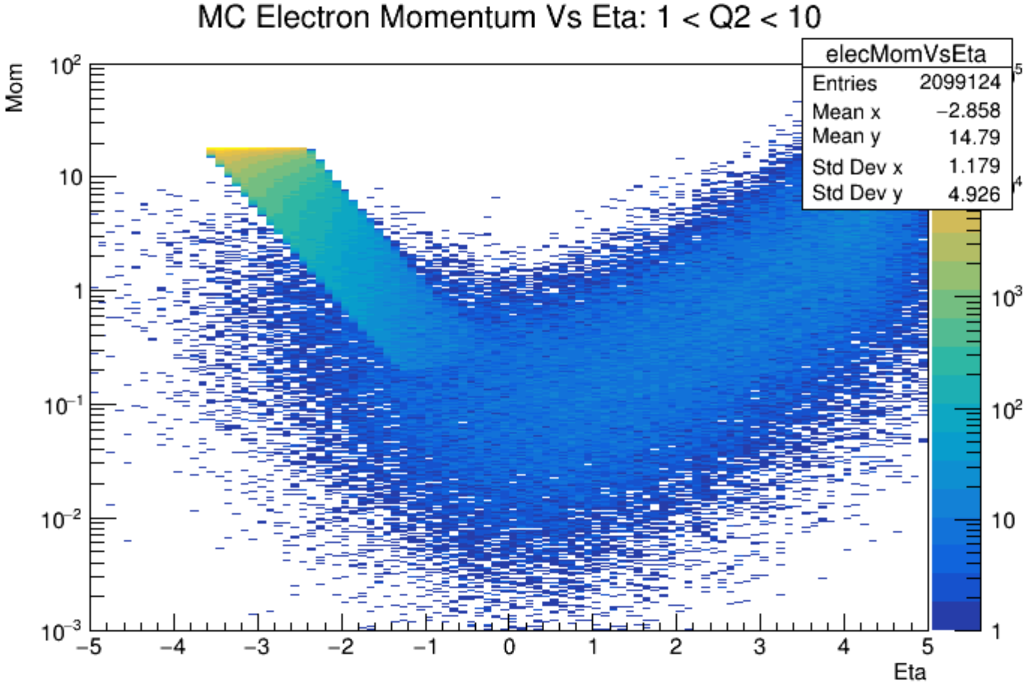
❑ Also look at tolerance of delta phi cut

Matched Electrons: True Mom/Eta



- ❑ Look at electron momentum vs pseudorapidity for pure MC (below) and reconstructed tracks with an associated particle (left)

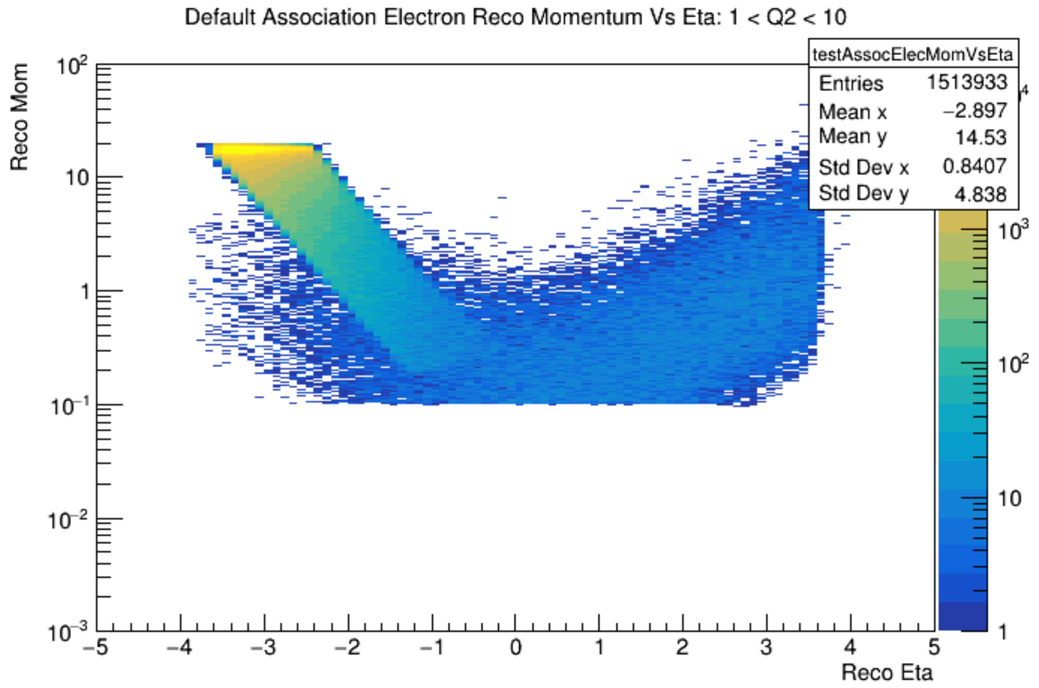
- ❑ True momentum and eta are plotted



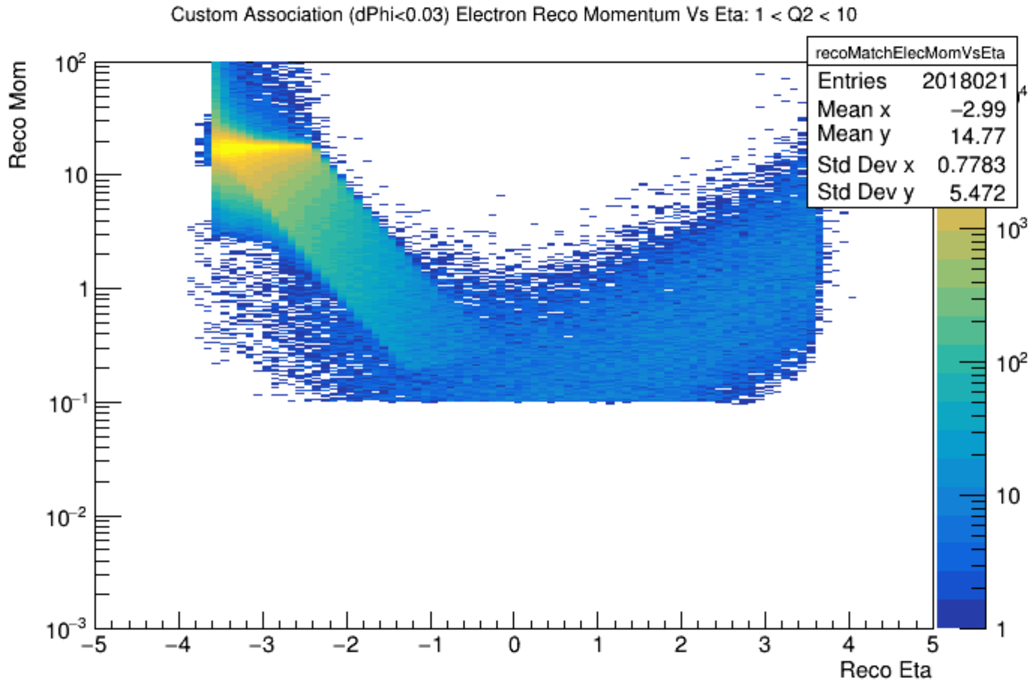
- ❑ The above plot shows the true momentum / eta of the track (ie that of the particle the track is matched to) and ratio of this plot to that on the right would give efficiency

- ❑ Next, look at momentum / eta of the reconstructed track itself

Matched Electrons: Reco Mom/Eta

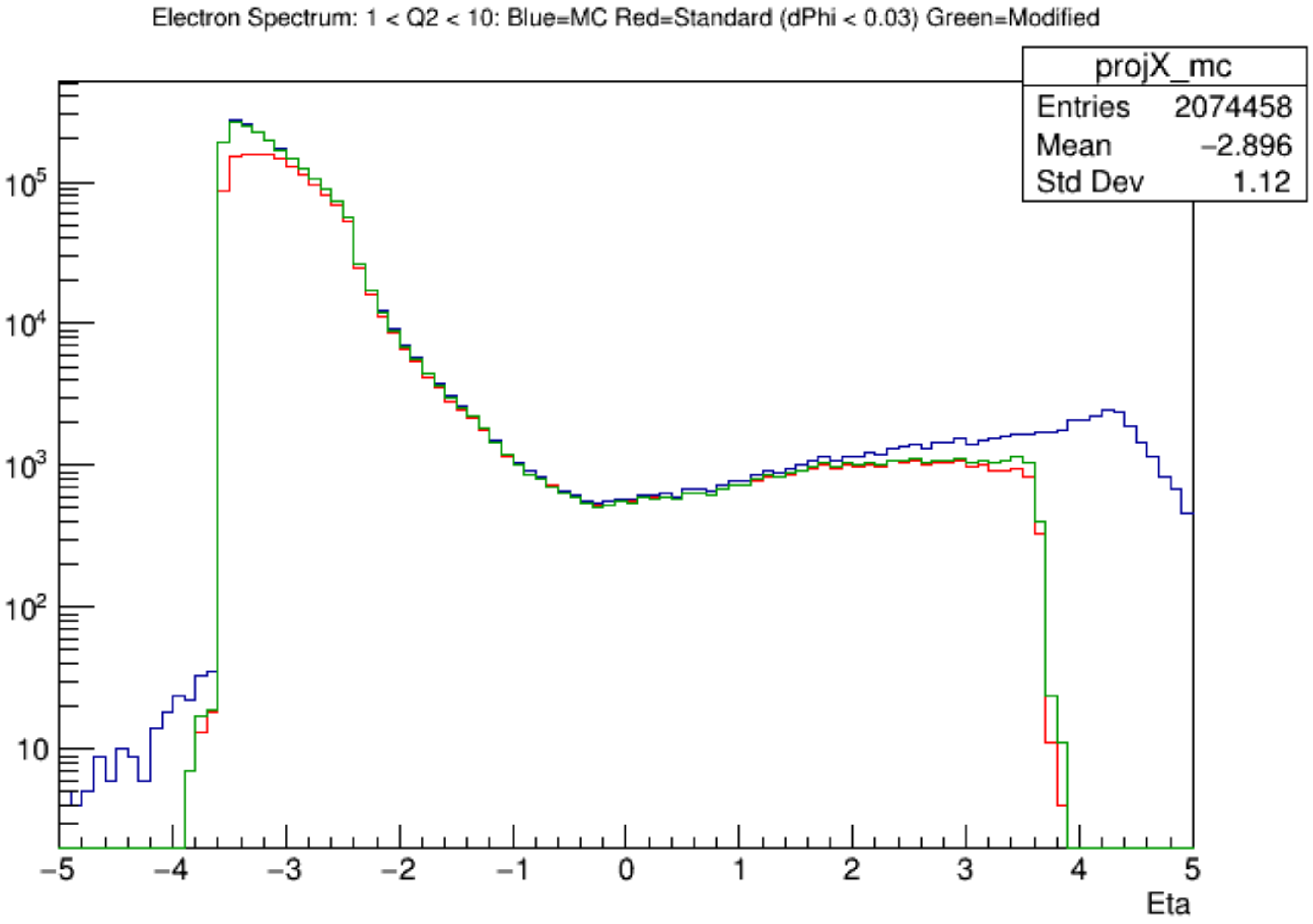


- ❑ Mild momentum spread is seen around the electron peak when looking at the reconstructed momentum of matched tracks for the default track-particle matching algo (left)
- ❑ Allowed momentum spread is capped at 10%



- ❑ Result of removing the momentum requirement in the track-particle matching can be seen on the right – significant spread, especially around the electron peak
- ❑ These tracks are still geometrically matched to a particle
- ❑ Ability to ‘see’ where momentum resolution goes bad will be important

Electron Efficiency Comparison: Delta Phi < 0.03



- ❑ Project previous plots onto the pseudorapidity axis to see how the track-particle matching algorithms perform

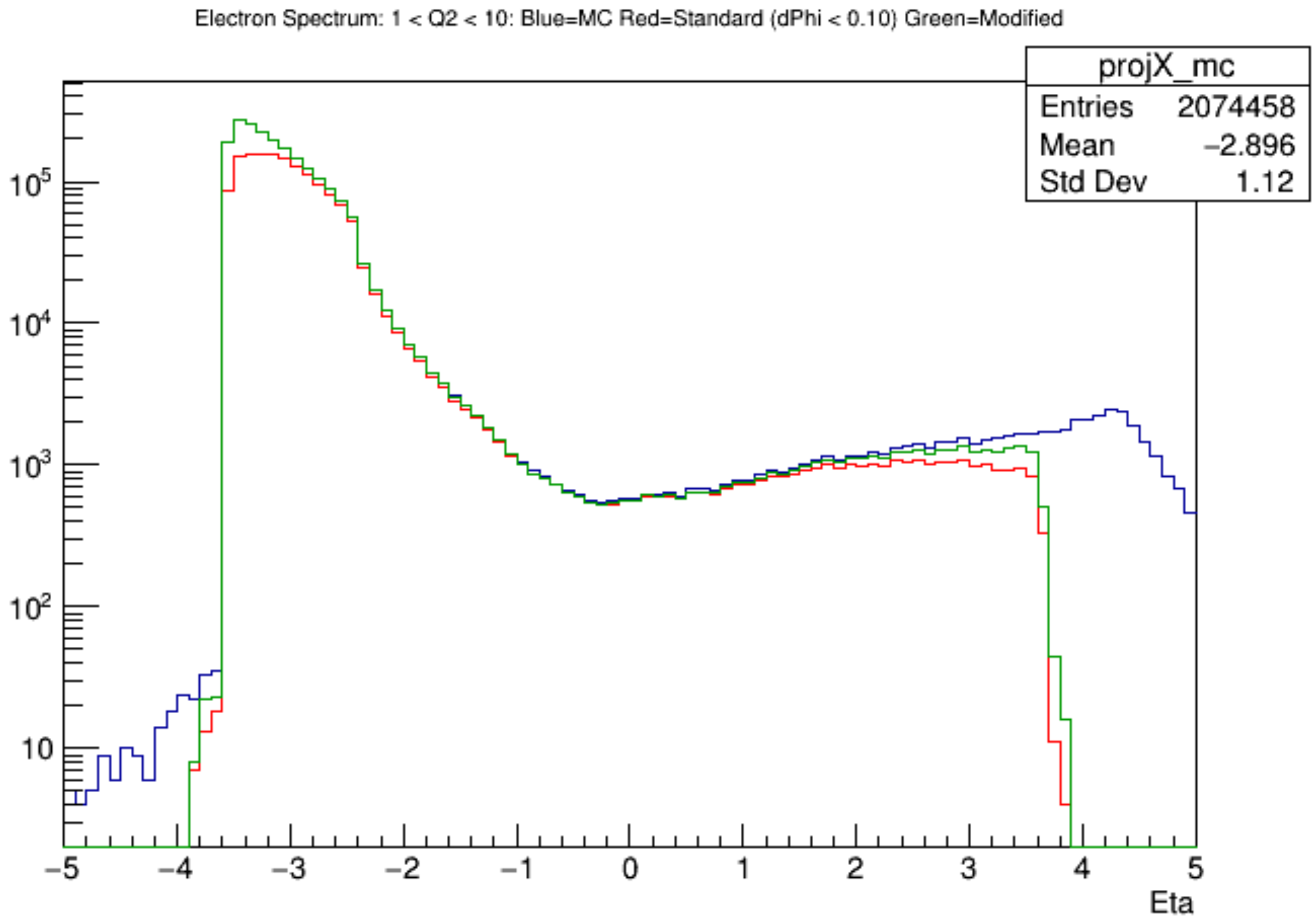
- ❑ True (particle) eta is plotted for matched tracks, but bin migration in eta will be small

- ❑ Blue is pure MC, Red is the default matching algorithm which includes the relative momentum cut of 10%, and green is the modified matching algorithm without the relative momentum cut

- ❑ Default matching algorithm misses tracks at high |eta|

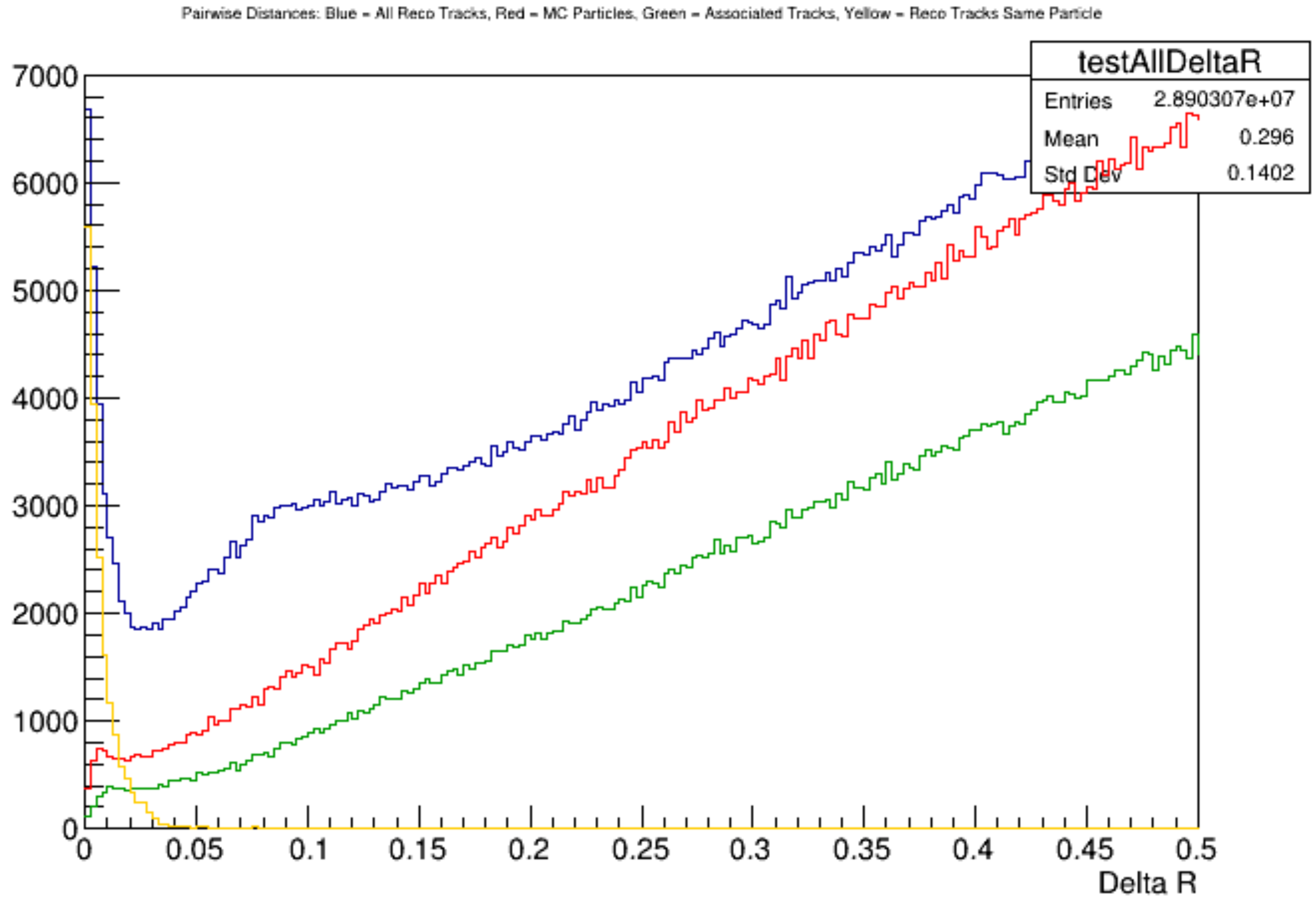
- ❑ Modified algo picks up the unmatched tracks in the electron peak region

Electron Efficiency Comparison: Delta Phi < 0.03



- ❑ Default matching algorithm uses a phi tolerance of 0.03 radians and requires track and particle to be within Sin(0.5*0.03) of each other
- ❑ This seemed a bit tight, so loosen the tolerance to 0.1 radians in the modified matching algorithm
- ❑ See further recovery of matched tracks, especially in eta > 1.5 region

Duplicate Tracks



- ❑ Found that some tracks were not matched to a particle by the default algorithm even though all criteria were satisfied
- ❑ Discovered these tracks had basically identical momentum, eta, phi as another in the same event
- ❑ Loop through all reconstructed tracks and calculate hypot(delta eta, delta phi) between each pair –blue curve). See a spike at ~0 Delta R
- ❑ Red curve shows the same for all (charged) MC particles and green for all tracks which have a particle associated with them as found by the default matching algo – no spike at zero found
- ❑ Yellow curve are track pairs which point to the same particle
- ❑ Want to raise awareness of this feature

Conclusion

- ❑ Current track-particle matching algorithm that fills ReconstructedChargedParticlesAssociation branch requires track and particle to have a relative momentum difference < 10%
- ❑ This requirement will cause tracks which are geometrically associated with particles, but with poorly reconstructed momentum to be considered unmatched – confuse efficiency and momentum resolution
- ❑ Proposal: Remove relative momentum condition from matching – also loosen delta phi tolerance from 0.03 to 0.10
- ❑ Also discovered some fraction of tracks seem to be duplicates – having nearly the same momentum, eta, phi. This is probably to be expected at some level, but analyzers need to be aware so they do not double count
- ❑ Duplicate tracks can be avoided by requiring a match to a particle