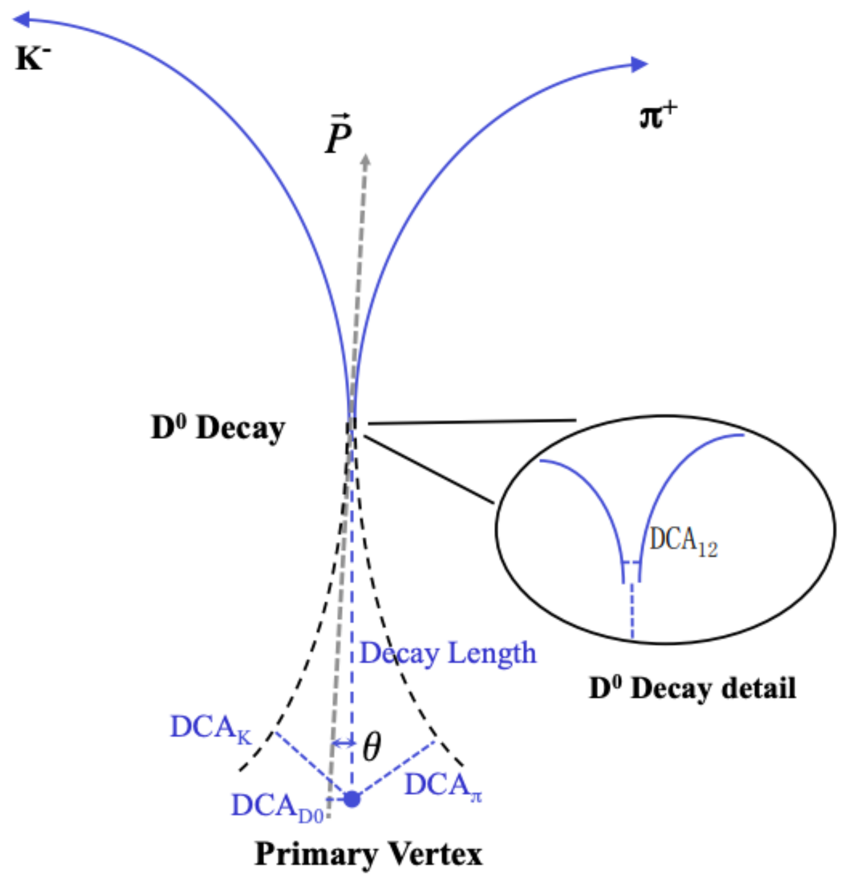
Helix and SecondaryVertices Factory in EICrecon

Xin Dong

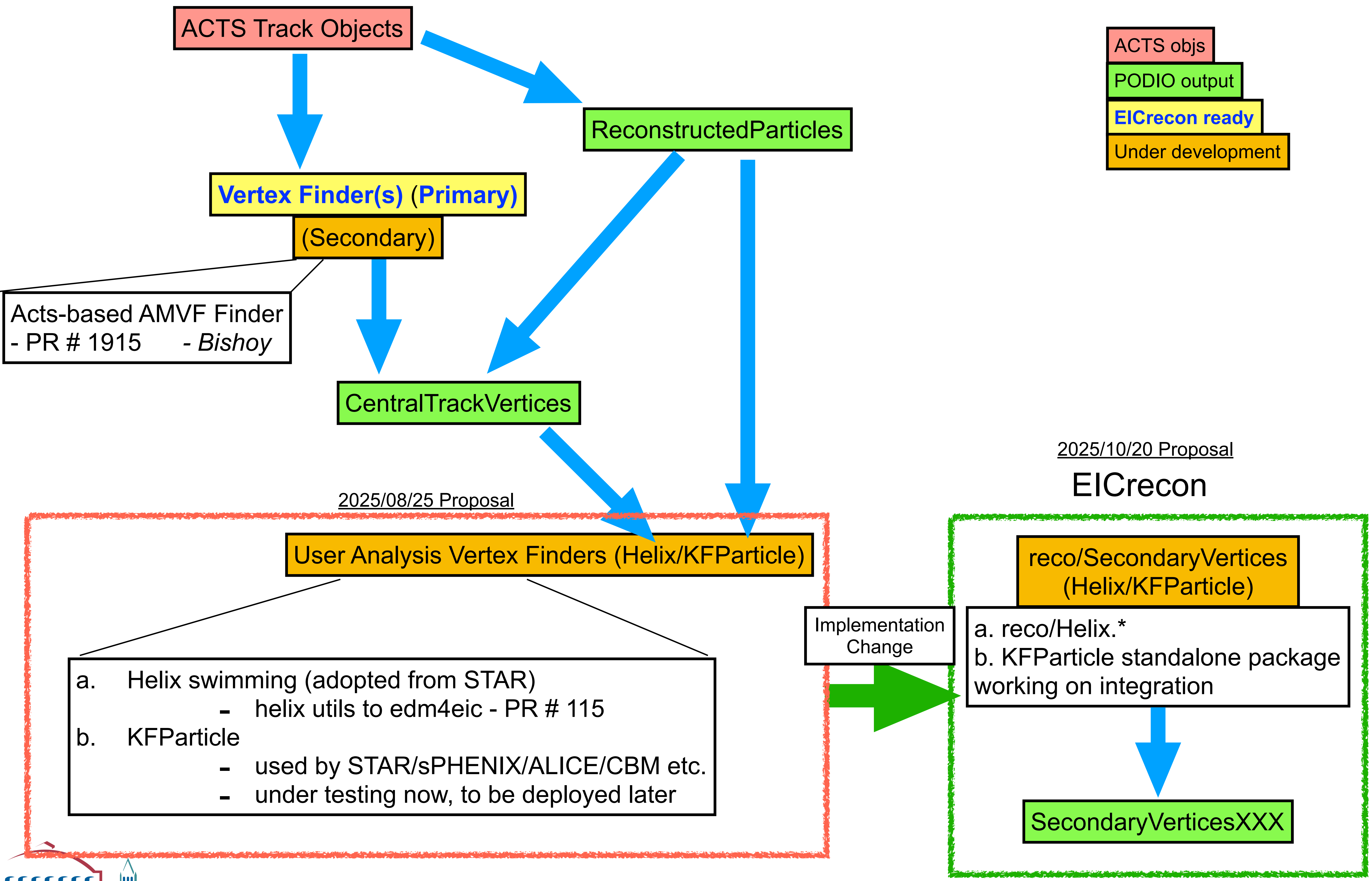


Thanks to:

Bishoy Dongwi, Lokesh Kumar, Rongrong Ma, Joe Osborn, Ashish Pandav, *Harsimran Singh*, *Khushi Singla*, Deepa Thomas, Connie Yang etc.

Previous presentation:
https://indico.bnl.gov/event/29424/contributions/112551/attachments/64322/110448/20250825_ePIC_Helix.pdf

Vertex Finders

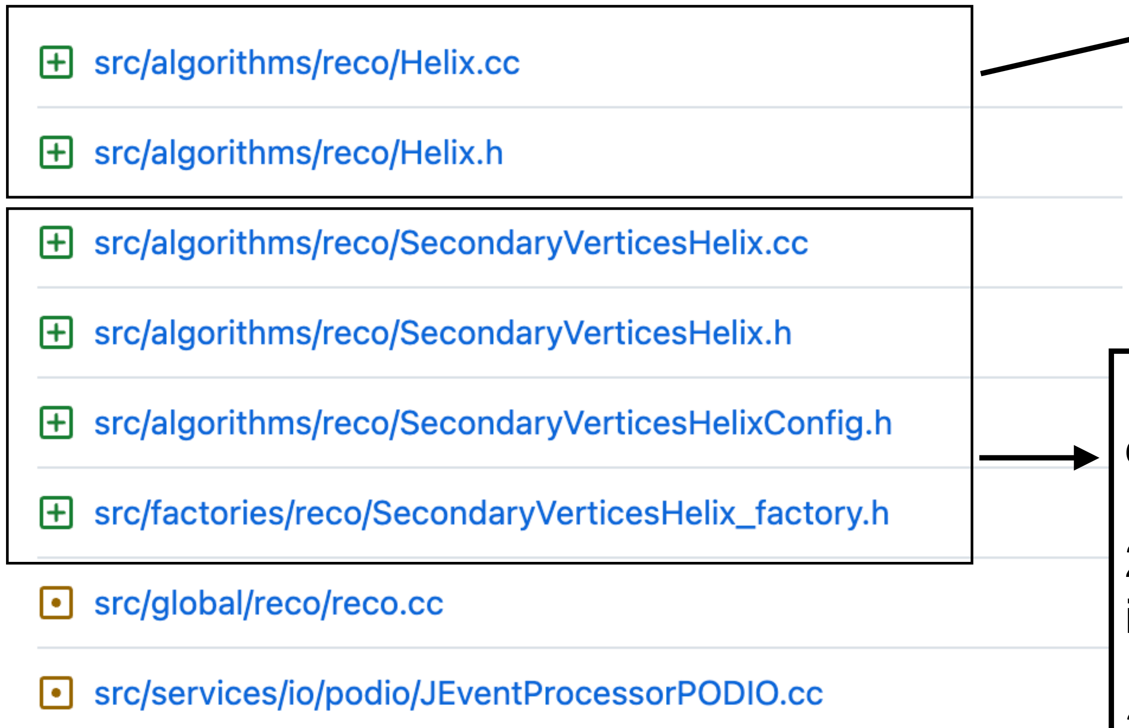


a. Helix swimming (adopted from STAR)
   - helix utils to edm4eic - PR # 115

b. KFParticle
   - used by STAR/sPHENIX/ALICE/CBM etc.
   - under testing now, to be deployed later

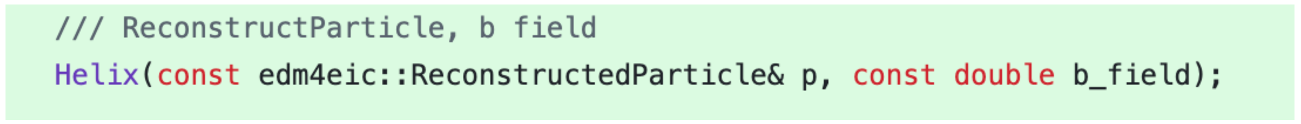
a. reco/Helix.*
b. KFParticle standalone package working on integration

EICrecon branch: pr/secondaryvertex-helix



- src/algorithms/reco/Helix.cc
- src/algorithms/reco/Helix.h
- src/algorithms/reco/SecondaryVerticesHelix.cc
- src/algorithms/reco/SecondaryVerticesHelix.h
- src/algorithms/reco/SecondaryVerticesHelixConfig.h
- src/factories/reco/SecondaryVerticesHelix_factory.h
- src/global/reco/reco.cc
- src/services/io/podio/JEventProcessorPODIO.cc

adopted from STAR code, adjusted for EICrecon



```
/// ReconstructParticle, b field
Helix(const edm4eic::ReconstructedParticle& p, const double b_field);
```

1. new SecondaryVertices factory, now based on Helix, can be expanded for others (e.g. KFParticle)

2. take ReconstructedParticle as input, run secondary finder (Ks included so far, can be expanded to include others)

3. output -> SecondaryVerticesHelix (edm4eic::Vertex) in PODIO
   - *proposed to add edm4eic::SecondaryVertex container (next slide)*

4. geometric cut variables controlled by SecondaryVerticesHelixConfig.h

All codes have been compiled in EICrecon, run successfully and produce meaningful output.

SecondaryVerticesHelix Factory

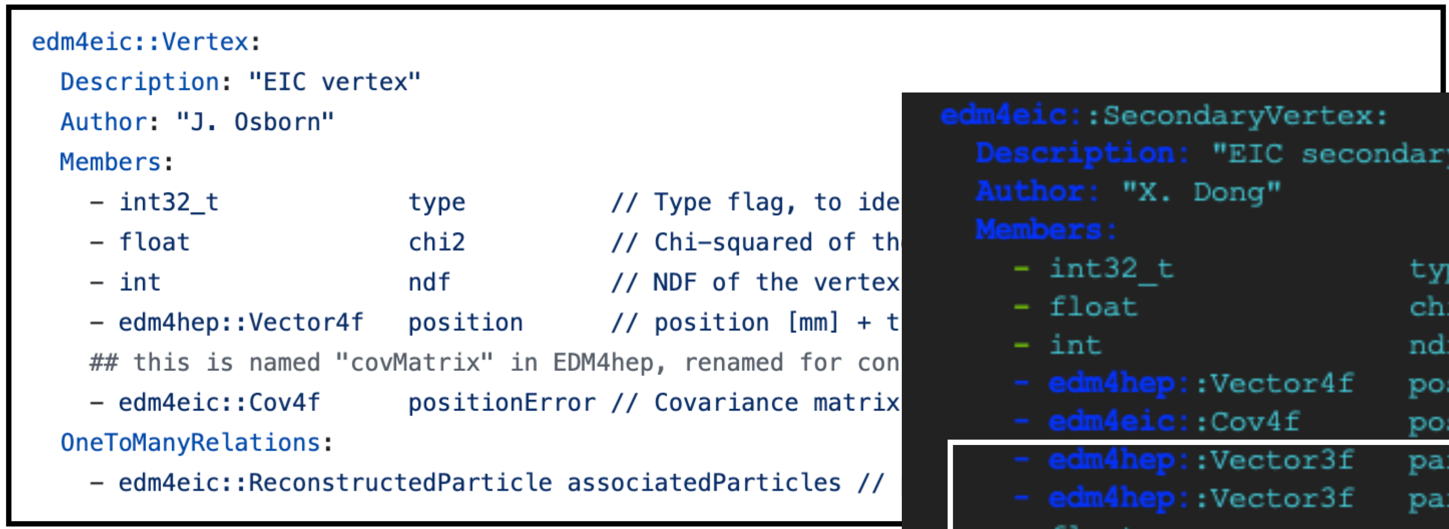
```cpp
void SecondaryVerticesHelix::process(const SecondaryVerticesHelix::Input& input,
                                     const SecondaryVerticesHelix::Output& output) const {
  const auto [rcvtx, rcparts] = input;
  auto [out_secondary_vertices] = output;

  auto& particleSvc = algorithms::ParticleSvc::instance();
//  edm4hep::Vector3f pVtxPos;
//  for(const auto& v : primVtx)
  const auto pVtxPos4f = (*rcvtx)[0].getPosition();
  // convert to cm
  edm4hep::Vector3f pVtxPos(pVtxPos4f.x*edm4eic::unit::mm/edm4e
                            pVtxPos4f.y*edm4eic::unit::mm/edm4e
                            pVtxPos4f.z*edm4eic::unit::mm/edm4e
  info("\t Primary vertex = ({},{},{})cm \t b field = {} tesla",
pVtxPos.z, m_cfg.b_field/dd4hep::tesla);

  std::vector<unsigned int> pi_index;
  std::vector<unsigned int> k_index;
  std::vector<unsigned int> p_index;
  for (unsigned int i = 0; const auto& p : *rcparts) {
    const auto pdg = p.getPDG();
    if(abs(pdg) == 211) pi_index.push_back(i);
    if(abs(pdg) == 321) k_index.push_back(i);
    if(abs(pdg) == 2212) p_index.push_back(i);
    ++i;
  }

  info("\t Array sizes: pions  = {}, kaons = {}, protons = {}",
k_index.size(), p_index.size());
```

```cpp
  for (unsigned int i1 = 0; i1 < pi_index.size(); ++i1) {
    for (unsigned int i2 = i1 + 1; i2 < pi_index.size(); ++i2) {
       const auto& p1 = (*rcparts)[i1];
       const auto& p2 = (*rcparts)[i2];

       if (p1.getCharge() + p2.getCharge() != 0) continue;

       Helix h1obj(p1, m_cfg.b_field);  Helix& h1 = h1obj;
       Helix h2obj(p2, m_cfg.b_field);  Helix& h2 = h2obj;

       // Helix function uses cm unit
       double dca1 = h1.distance(pVtxPos) * edm4eic::unit::cm;
       double dca2 = h2.distance(pVtxPos) * edm4eic::unit::cm;
       debug("\t dca1 = {}, dca2 = {}", dca1, dca2);
       if( dca1 < m_cfg.minDca1 || dca2 < m_cfg.minDca2 ) continue;

       std::pair<double, double> const ss = h1.pathLengths(h2);
       edm4hep::Vector3f h1AtDcaTo2 = h1.at(ss.first);
       edm4hep::Vector3f h2AtDcaTo1 = h2.at(ss.second);

       double dca12 = edm4hep::utils::magnitude(h1AtDcaTo2 - h2AtDcaTo1) *
edm4eic::unit::cm;
       if( dca12 > m_cfg.maxDca12 ) continue;
       edm4hep::Vector3f pairPos = 0.5*(h1AtDcaTo2 + h2AtDcaTo1);

       edm4hep::Vector3f h1MomAtDca = h1.momentumAt(ss.first, m_cfg.b_field);
       edm4hep::Vector3f h2MomAtDca = h2.momentumAt(ss.second, m_cfg.b_field);
       edm4hep::Vector3f pairMom = h1MomAtDca + h2MomAtDca;

       float e1 = std::hypot(edm4hep::utils::magnitude(h1MomAtDca),
particleSvc.particle(211).mass);
       float e2 = std::hypot(edm4hep::utils::magnitude(h2MomAtDca),
particleSvc.particle(211).mass);
       float pairE = e1+e2;

       edm4hep::Vector4f h1FourMom(h1MomAtDca.x, h1MomAtDca.y, h1MomAt
       edm4hep::Vector4f h2FourMom(h2MomAtDca.x, h2MomAtDca.y, h2MomAt

       double m_inv = std::hypot(pairE, -edm4hep::utils::magnitude(pai
       double angle = edm4hep::utils::angleBetween(pairMom, pairPos - |
       if(cos(angle) < m_cfg.minCostheta ) continue;
```

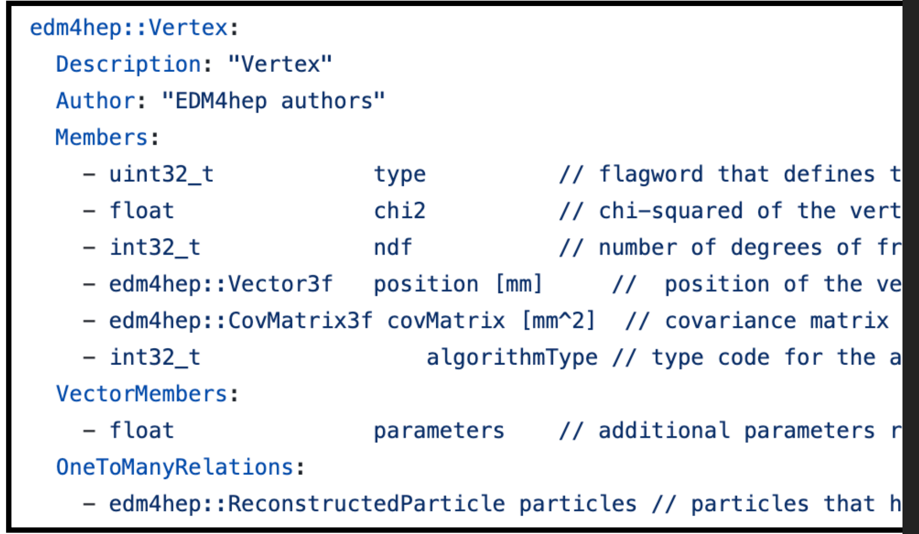
```cpp
       double beta = edm4hep::utils::magnitude(pairMom)/pairE;
       double time = edm4hep::utils::magnitude(pairPos - pVtxPos)/(beta*dd4hep::c_light);
       auto v0 = out_secondary_vertices->create();
       v0.setType(2); // 2 for secondary
       v0.setPosition({(float)(pairPos.x * edm4eic::unit::cm / edm4eic::unit::mm),
                       (float)(pairPos.y * edm4eic::unit::cm / edm4eic::unit::mm),
                       (float)(pairPos.z * edm4eic::unit::cm / edm4eic::unit::mm),
                       (float)time});
       v0.addToAssociatedParticles(p1);
       v0.addToAssociatedParticles(p2);

       info("One secondary vertex found at (x,y,z) = ({}, {}, {}) mm.",
             pairPos.x * edm4eic::unit::cm / edm4eic::unit::mm,
             pairPos.y * edm4eic::unit::cm / edm4eic::unit::mm,
             pairPos.x * edm4eic::unit::cm / edm4eic::unit::mm);

    } // end i2
  } // end i1

} // end process
```

SecondaryVertex to edm4eic: add-secondaryvertex branch

1. Current edm4eic::vertex object doesn’t contain many topological variables for secondary vertices.
2. Though one can in principle re-calculate all these based on the associated ReconstructedParticle, it will be much more convenient to save them during reconstruction and the down-stream analysis can directly use them for physics analysis and also this will avoid repeated calculations.

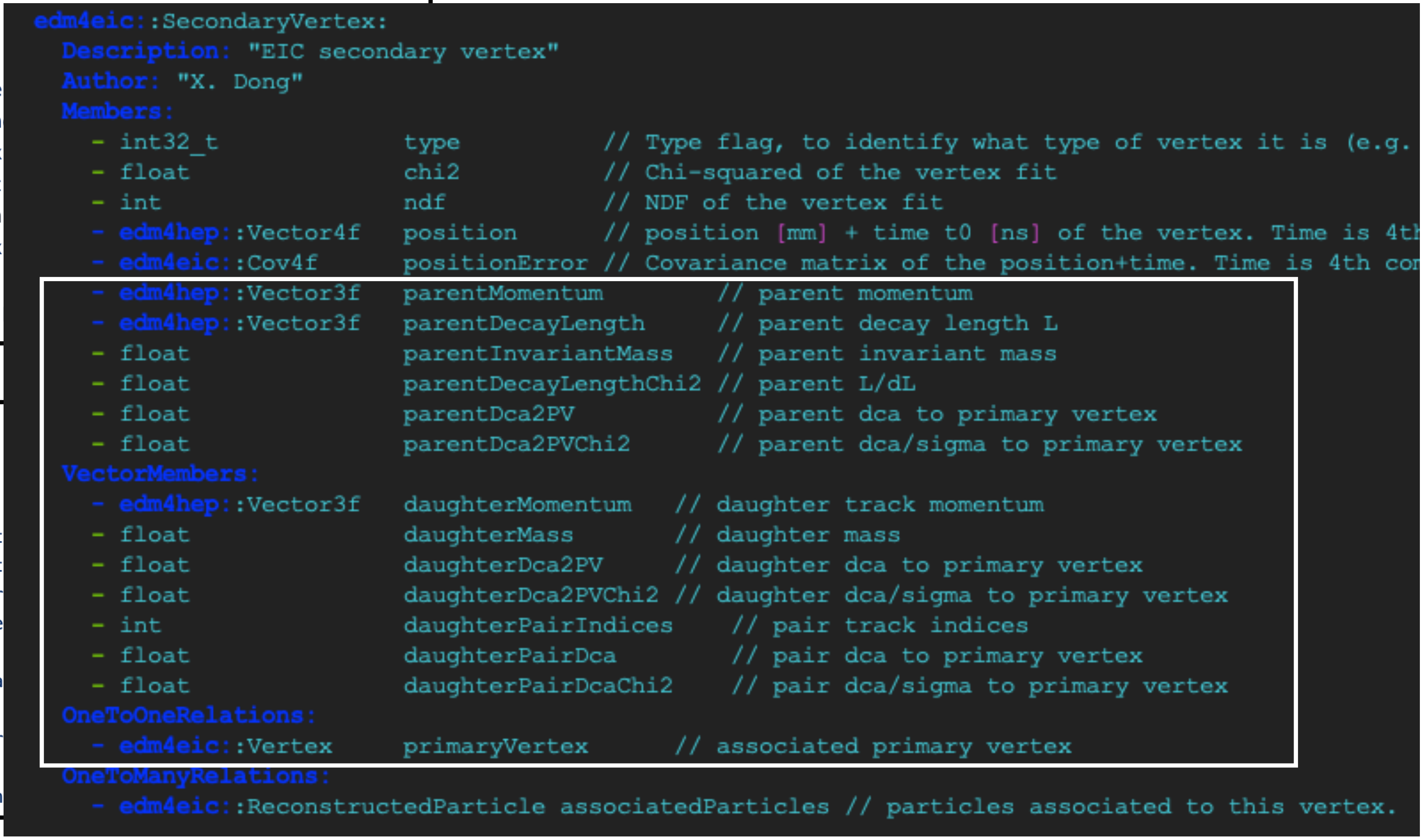


```
edm4eic::Vertex:
  Description: "EIC vertex"
  Author: "J. Osborn"
  Members:
    - int32_t             type          // Type flag, to ide
    - float               chi2          // Chi-squared of th
    - int                 ndf           // NDF of the vertex
    - edm4hep::Vector4f   position      // position [mm] + t
    ## this is named "covMatrix" in EDM4hep, renamed for con
    - edm4eic::Cov4f      positionError // Covariance matrix
  OneToManyRelations:
    - edm4eic::ReconstructedParticle associatedParticles //
```



```
edm4hep::Vertex:
  Description: "Vertex"
  Author: "EDM4hep authors"
  Members:
    - uint32_t            type          // flagword that defines t
    - float               chi2          // chi-squared of the vert
    - int32_t             ndf           // number of degrees of fr
    - edm4hep::Vector3f   position [mm]     //  position of the ve
    - edm4hep::CovMatrix3f covMatrix [mm^2]  // covariance matrix
    - int32_t                 algorithmType // type code for the a
  VectorMembers:
    - float               parameters    // additional parameters r
  OneToManyRelations:
    - edm4hep::ReconstructedParticle particles // particles that h
```

<u>Propose to add edm4eic::SecondaryVertex container</u>

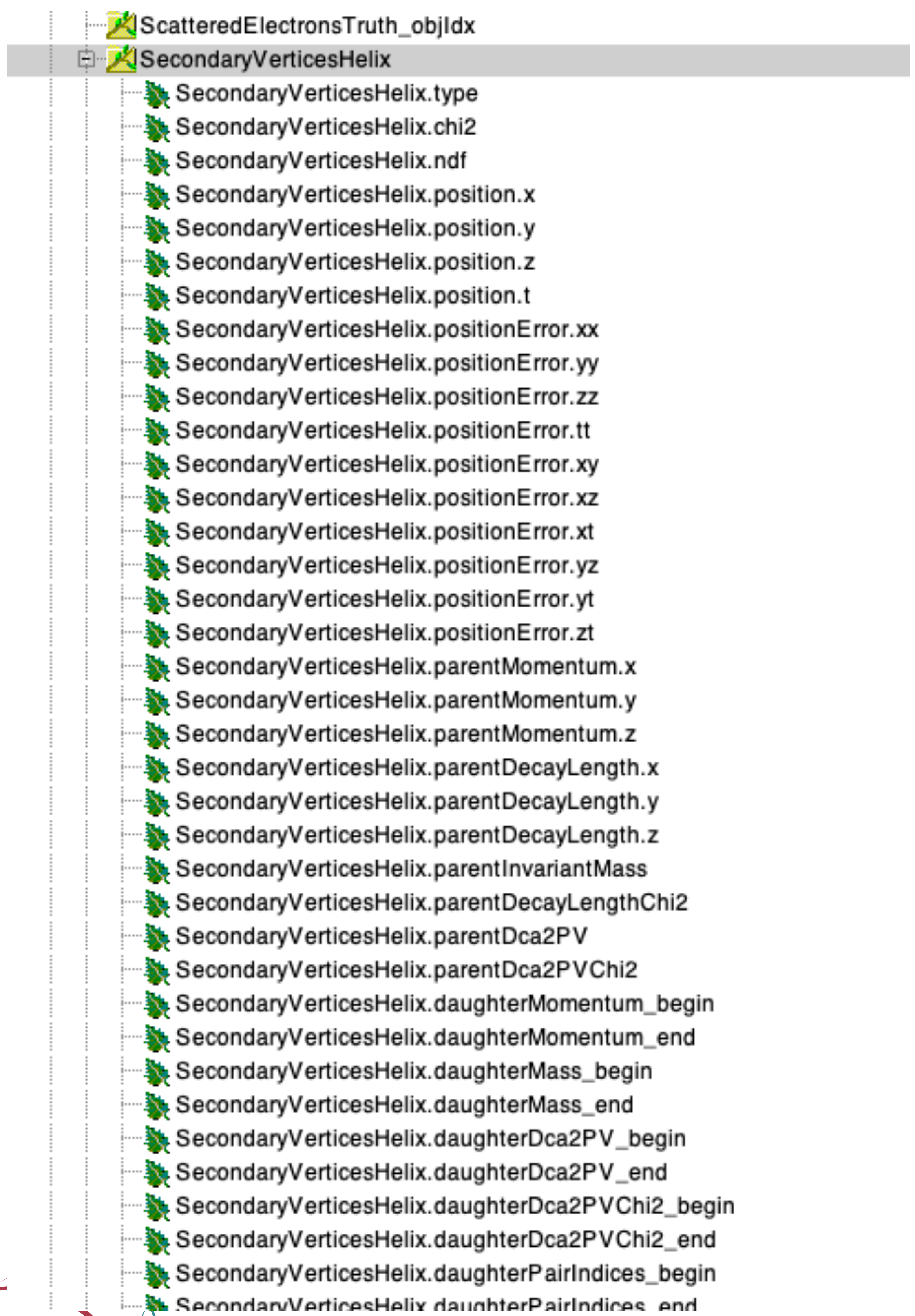


```
edm4eic::SecondaryVertex:
  Description: "EIC secondary vertex"
  Author: "X. Dong"
  Members:
    - int32_t             type          // Type flag, to identify what type of vertex it is (e.g.
    - float               chi2          // Chi-squared of the vertex fit
    - int                 ndf           // NDF of the vertex fit
    - edm4hep::Vector4f   position      // position [mm] + time t0 [ns] of the vertex. Time is 4th
    - edm4eic::Cov4f      positionError // Covariance matrix of the position+time. Time is 4th co
    - edm4hep::Vector3f   parentMomentum          // parent momentum
    - edm4hep::Vector3f   parentDecayLength       // parent decay length L
    - float               parentInvariantMass     // parent invariant mass
    - float               parentDecayLengthChi2   // parent L/dL
    - float               parentDca2PV            // parent dca to primary vertex
    - float               parentDca2PVChi2        // parent dca/sigma to primary vertex
  VectorMembers:
    - edm4hep::Vector3f   daughterMomentum     // daughter track momentum
    - float               daughterMass         // daughter mass
    - float               daughterDca2PV       // daughter dca to primary vertex
    - float               daughterDca2PVChi2   // daughter dca/sigma to primary vertex
    - int                 daughterPairIndices      // pair track indices
    - float               daughterPairDca          // pair dca to primary vertex
    - float               daughterPairDcaChi2      // pair dca/sigma to primary vertex
  OneToOneRelations:
    - edm4eic::Vertex     primaryVertex        // associated primary vertex
  OneToManyRelations:
    - edm4eic::ReconstructedParticle associatedParticles // particles associated to this vertex.
```

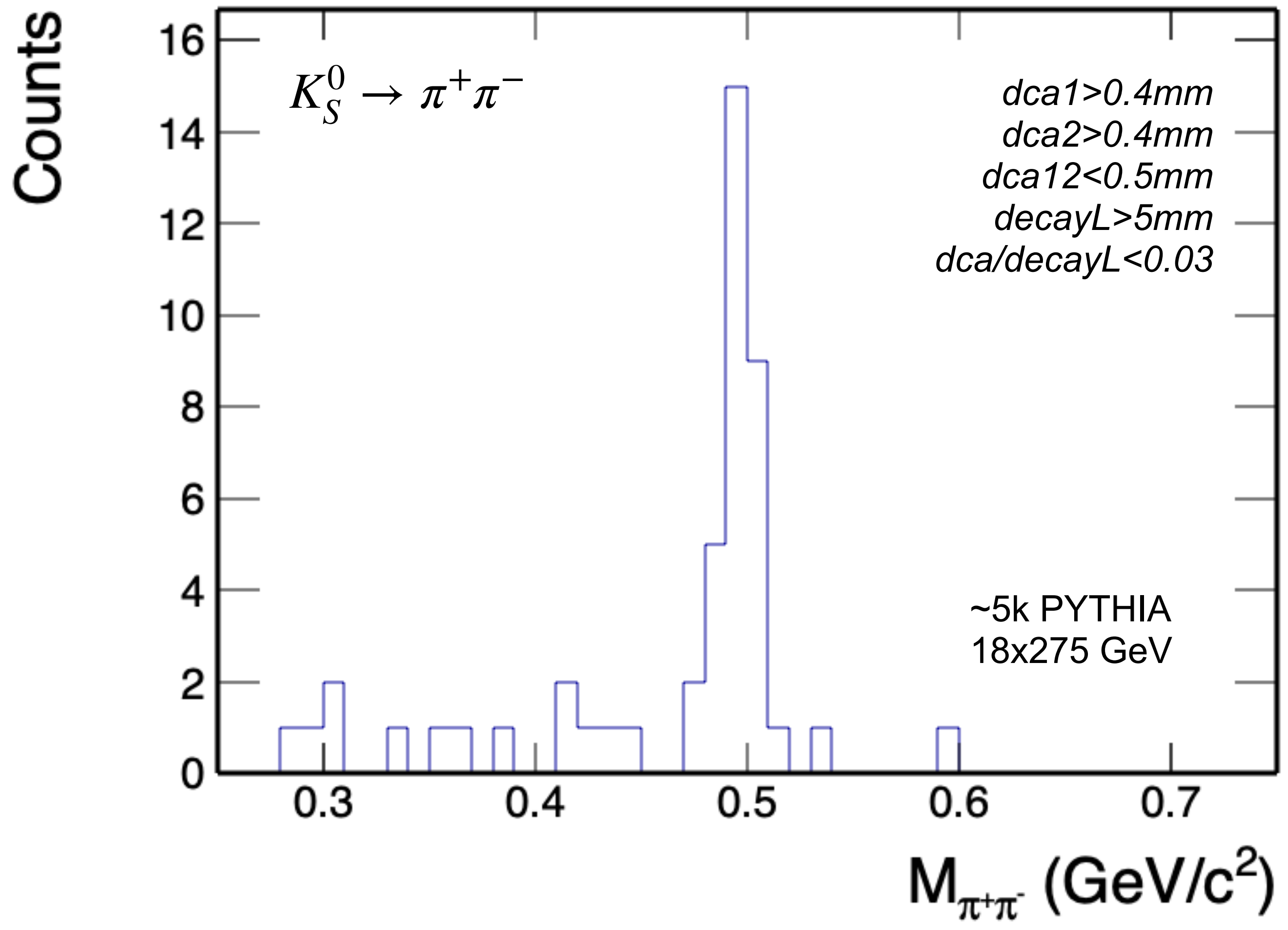
New structure has been integrated to EICrecon locally and tested to work well!
A new brunch add-secondaryvertex on edm4eic repo.

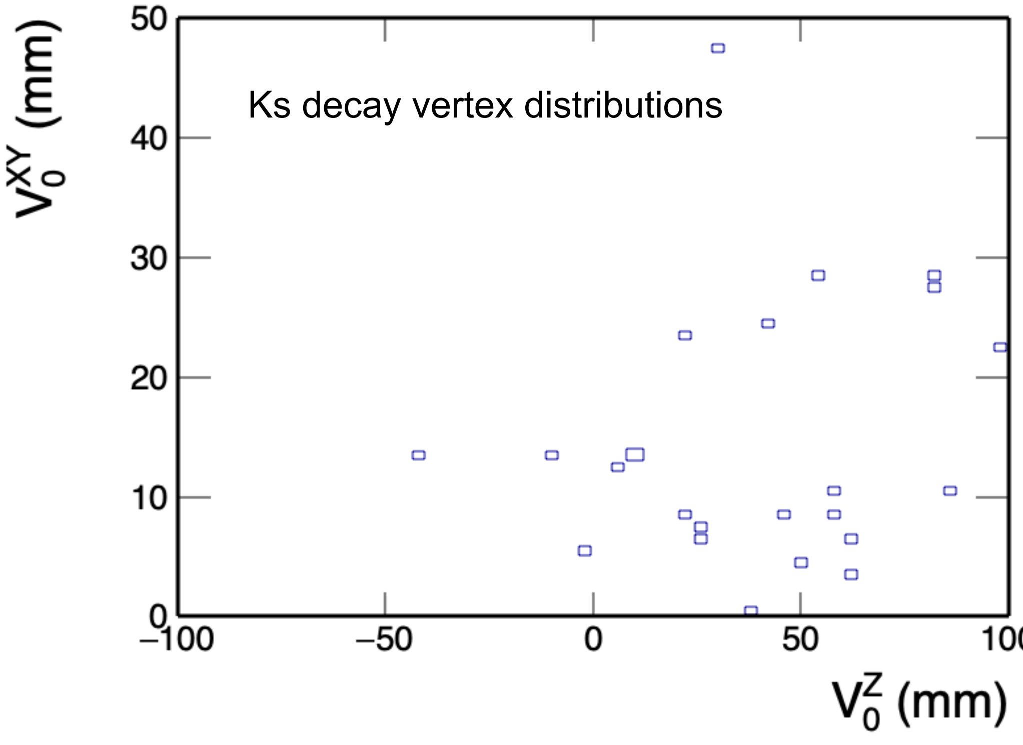
Test Output

PODIO output



```
ScatteredElectronsTruth_objIdx
SecondaryVerticesHelix
    SecondaryVerticesHelix.type
    SecondaryVerticesHelix.chi2
    SecondaryVerticesHelix.ndf
    SecondaryVerticesHelix.position.x
    SecondaryVerticesHelix.position.y
    SecondaryVerticesHelix.position.z
    SecondaryVerticesHelix.position.t
    SecondaryVerticesHelix.positionError.xx
    SecondaryVerticesHelix.positionError.yy
    SecondaryVerticesHelix.positionError.zz
    SecondaryVerticesHelix.positionError.tt
    SecondaryVerticesHelix.positionError.xy
    SecondaryVerticesHelix.positionError.xz
    SecondaryVerticesHelix.positionError.xt
    SecondaryVerticesHelix.positionError.yz
    SecondaryVerticesHelix.positionError.yt
    SecondaryVerticesHelix.positionError.zt
    SecondaryVerticesHelix.parentMomentum.x
    SecondaryVerticesHelix.parentMomentum.y
    SecondaryVerticesHelix.parentMomentum.z
    SecondaryVerticesHelix.parentDecayLength.x
    SecondaryVerticesHelix.parentDecayLength.y
    SecondaryVerticesHelix.parentDecayLength.z
    SecondaryVerticesHelix.parentInvariantMass
    SecondaryVerticesHelix.parentDecayLengthChi2
    SecondaryVerticesHelix.parentDca2PV
    SecondaryVerticesHelix.parentDca2PVChi2
    SecondaryVerticesHelix.daughterMomentum_begin
    SecondaryVerticesHelix.daughterMomentum_end
    SecondaryVerticesHelix.daughterMass_begin
    SecondaryVerticesHelix.daughterMass_end
    SecondaryVerticesHelix.daughterDca2PV_begin
    SecondaryVerticesHelix.daughterDca2PV_end
    SecondaryVerticesHelix.daughterDca2PVChi2_begin
    SecondaryVerticesHelix.daughterDca2PVChi2_end
    SecondaryVerticesHelix.daughterPairIndices_begin
    SecondaryVerticesHelix.daughterPairIndices_end
```





Summary

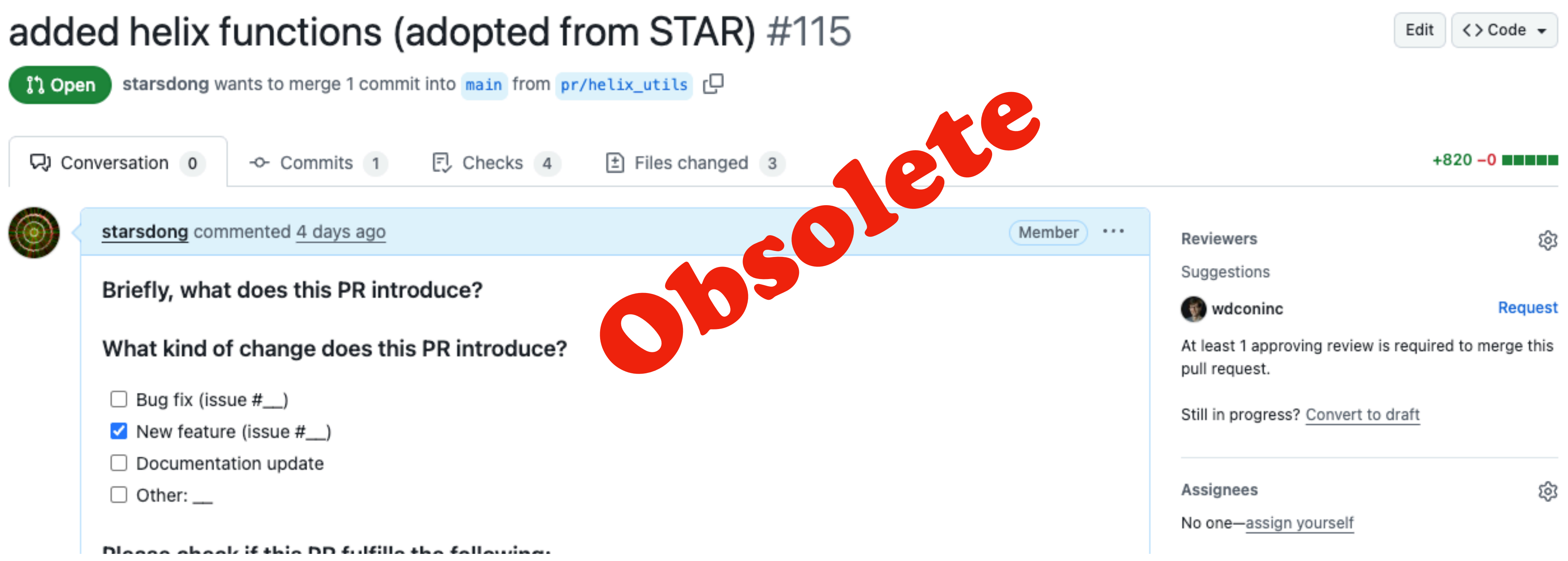
1. If this approach is agreed on, we plan to submit the PR based on pr/secondaryvertex-helix first
   - current version is working with edm4eic::Vertex container

2. We will propose a new edm4eic container: SecondaryVertex (add-secondaryvertex brunch)
   - once this is added to edm4eic, will update SecondaryVertexHelix_factory then.

3. Continue the development of secondary VFs (Helix with more particles included, KFParticle etc.)

Backup

Adding Helix Functions in EDM4eic (obsolete!)



added helix functions (adopted from STAR) #115

Open starsdong wants to merge 1 commit into `main` from `pr/helix_utils`

starsdong commented 4 days ago

Briefly, what does this PR introduce?

What kind of change does this PR introduce?

- [ ] Bug fix (issue #__)
- [x] New feature (issue #__)
- [ ] Documentation update
- [ ] Other: __

Please check if this PR fulfills the following:

Reviewers

Suggestions

wdconinc Request

At least 1 approving review is required to merge this pull request.

Still in progress? Convert to draft

Assignees

No one—assign yourself

1) Helix afterburner reconstruction is used in D^0 reconstruction (later part), targeted to be used for updated physics projection plots.

2) Constructor includes using EICrecon TrackParameters as input.

3) Handling constant z-magnetic field (or zero field - straight-line)

- can be extended to handle varying B-field for track projection

4) Iterative varying-step-scan to find DCA positions between helices numerically.

Usage of Helix Method

Helix method has been used in many heavy flavor hadron analysis (Rongrong/Shyam/Connie etc.)

pre-TDR

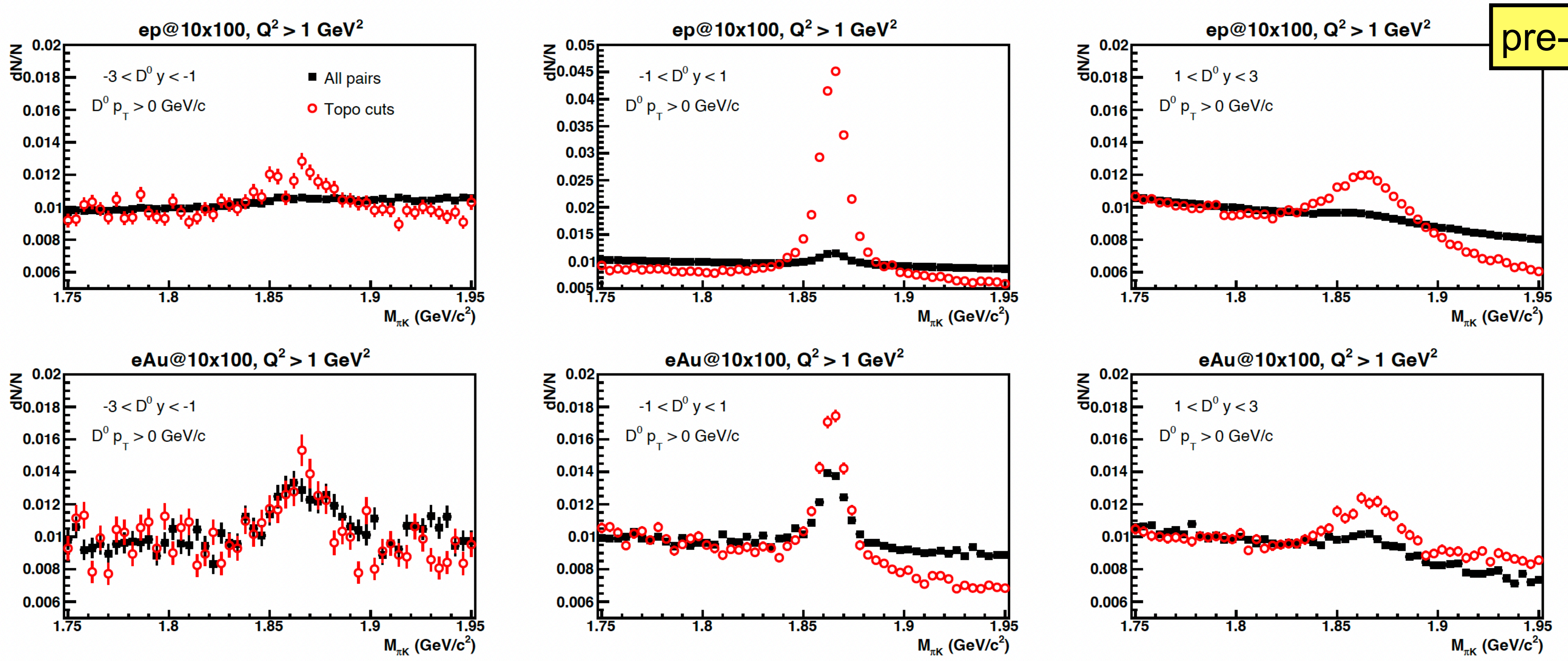


Figure 2.22: Invariant mass distributions of $\pi + K$ pairs with (red circles) and without (black squares) topological selections in 10×100 GeV e+p (top) and e+Au (bottom) collisions with a minimum Q^2 of 1 GeV^2. Different panels from left to right correspond to different D^0 rapidity intervals: $-3 < y < -1$ (left), $-1 < y < 1$ (middle) and $1 < y < 3$ (right).

Example of using Helix method:
https://github.com/marrbnl/ePIC/tree/main/HF_reco/helix