Vertex charge reconstruction in ILD
Technical overview

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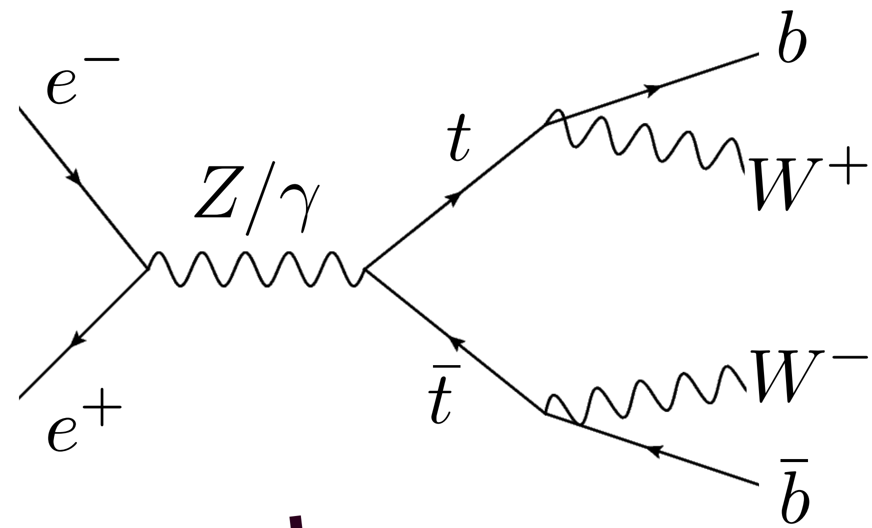
ECFA workshop 31/05/16

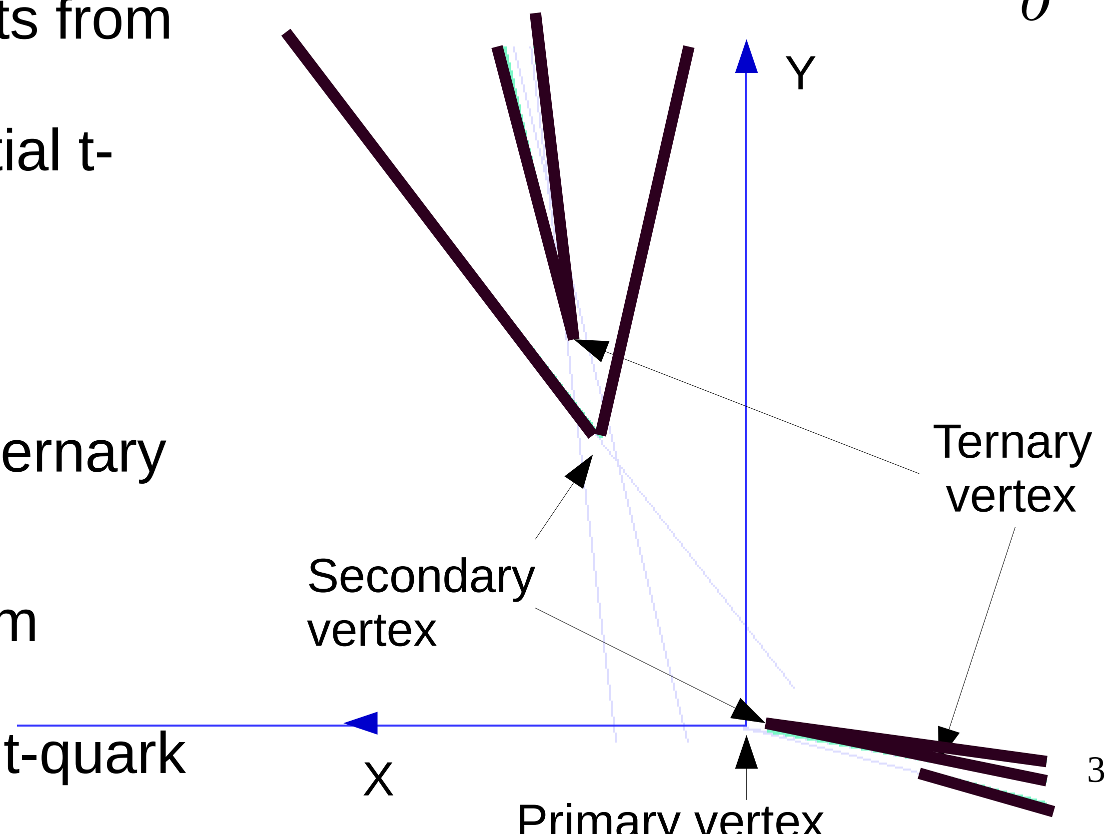
Overview

- ➔ **Introduction**
- TruthVertexFinder
- Reconstruction validation
- VertexChargeRecovery

Objective

- Main purpose of this work is to detect the charge of top and antitop quarks. This is crucial for calculation of forward-backward asymmetry A_{fb} in $t\bar{t}$ process at ILC
- Properties of decay products from the B-hadrons are used to determine the charge of initial t-quark
- Charge of the b-quark is calculated as a sum of the charges of secondary and ternary vertex particles
- The charge of K-meson from ternary vertex is directly connected to the charge of t-quark

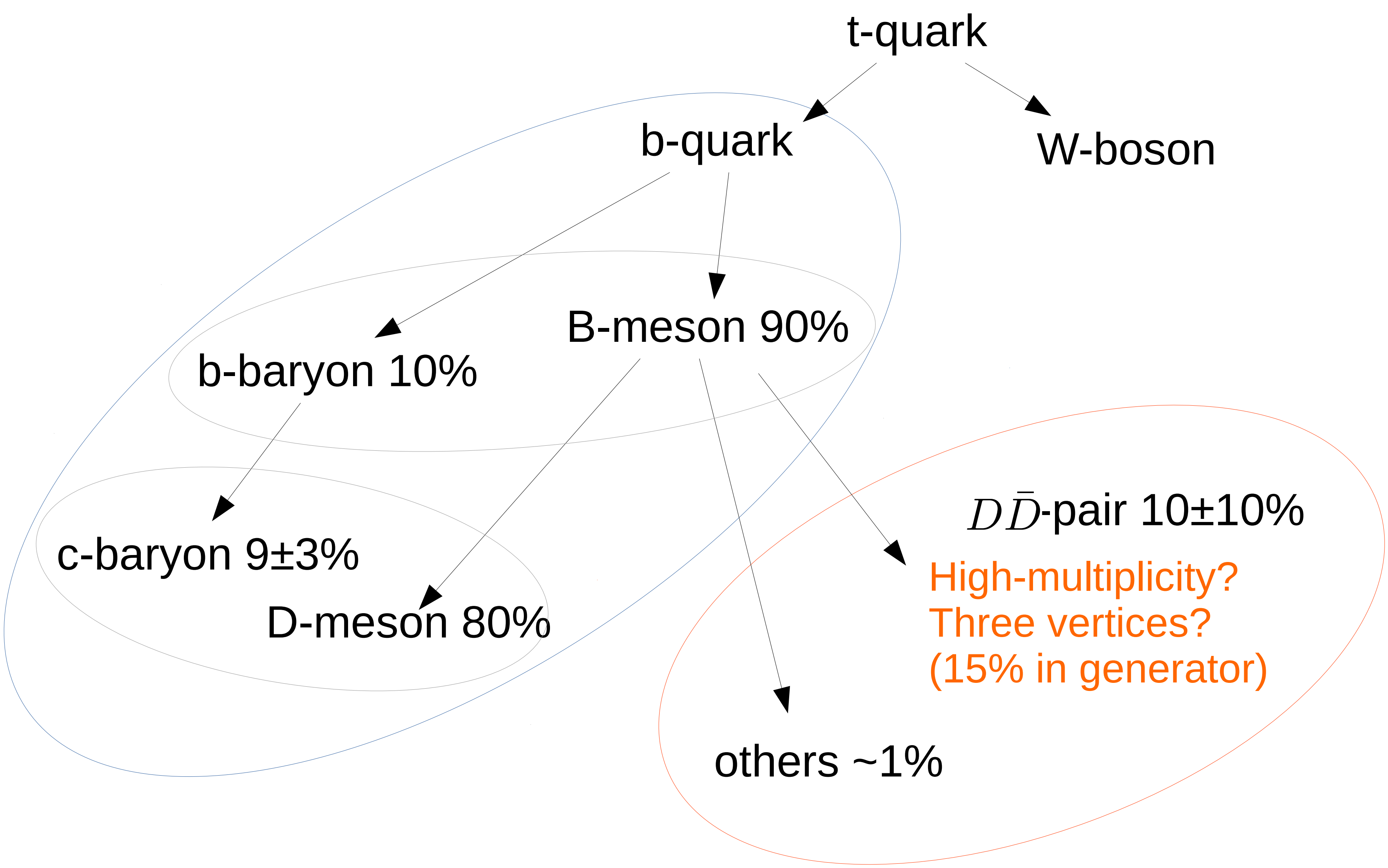




- Introduction
- → **TruthVertexFinder**
- Reconstruction validation
- VertexChargeRecovery

Process overview

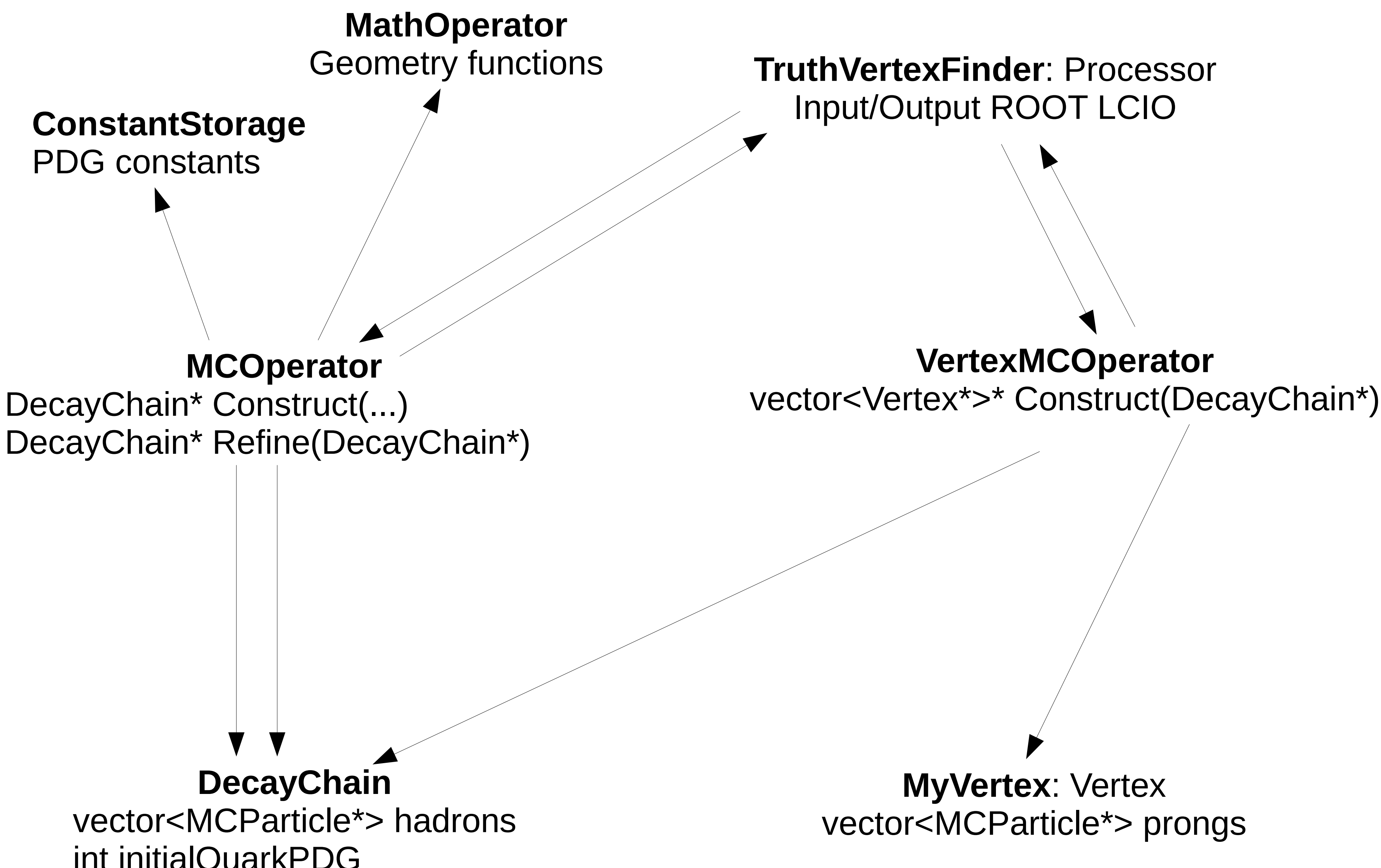
- Hadronization and decay modes of b-quark:



TruthVertexFinder IO

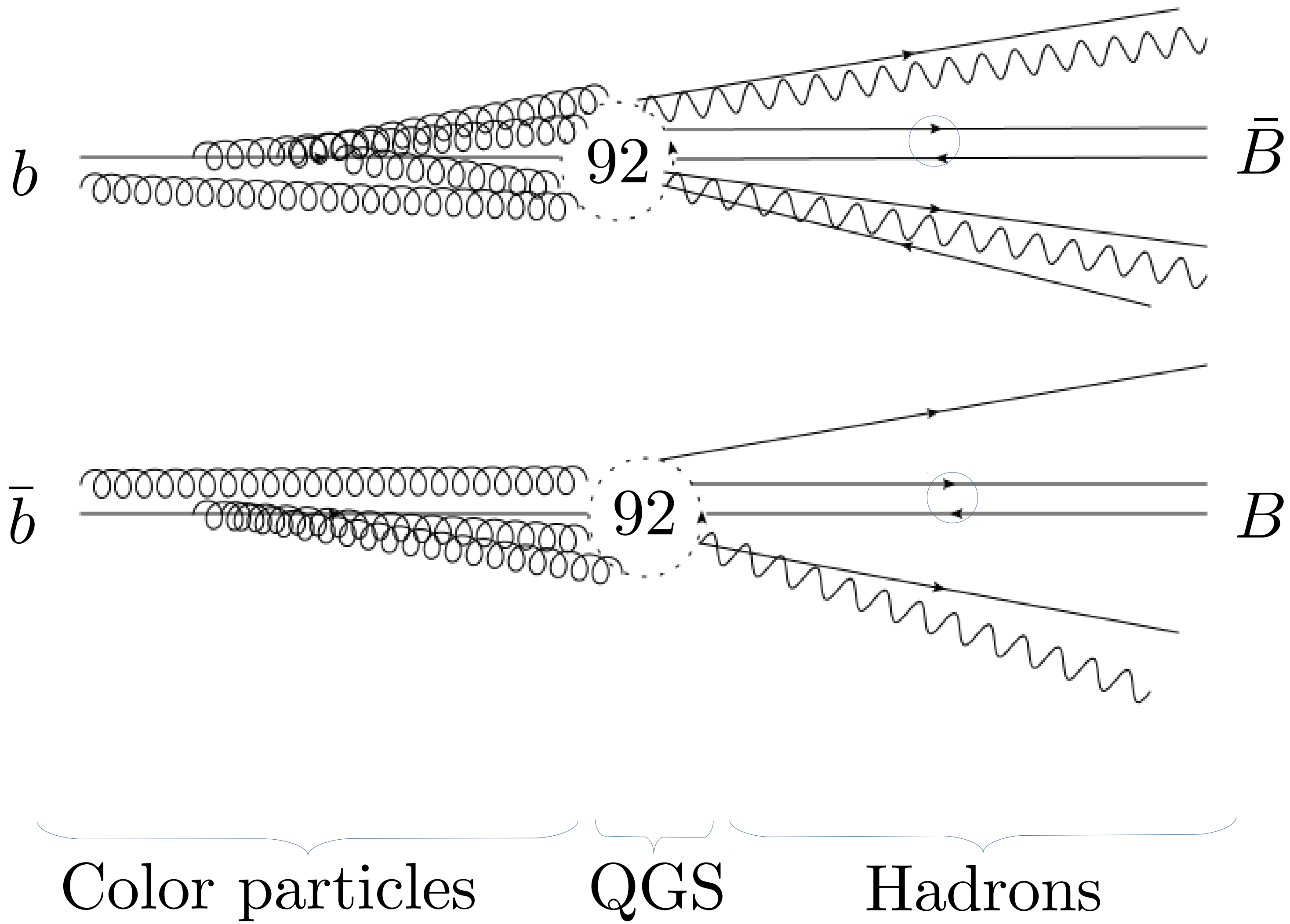
- Input
  - CollectionName (string) – Name of generated particles collection
  - InitialQuarkPDG (int) – PDG code of the seeding quark. Ex: 5
  - DecayChainPDGs (vector<int>) - list of the hadron types that are used to form the generated vertices. Each entry will seed a formation of a generated vertex. Ex: input of “5500 4400 0” will form a secondary vertex of b-hadrons and a ternary vertex of c-hadrons
- Output
  - EGProngs (MCParticle*) - collection of generated prongs from all found vertices
  - MCVertex (Vertex*) - collection of found generated vertices

TruthVertexFinder scheme



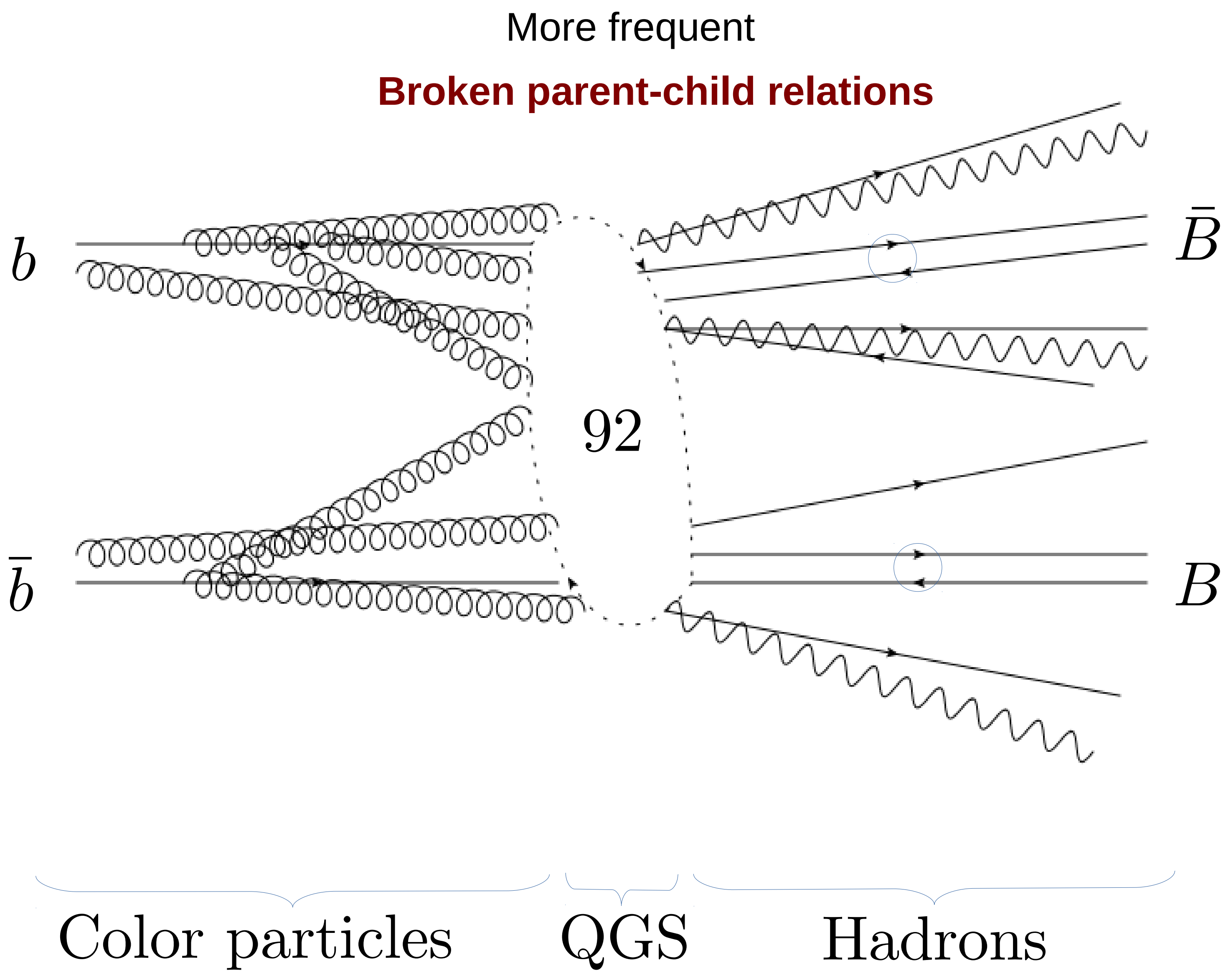
Process overview

- Hadronization of the b-quarks in the MCParticles collection:



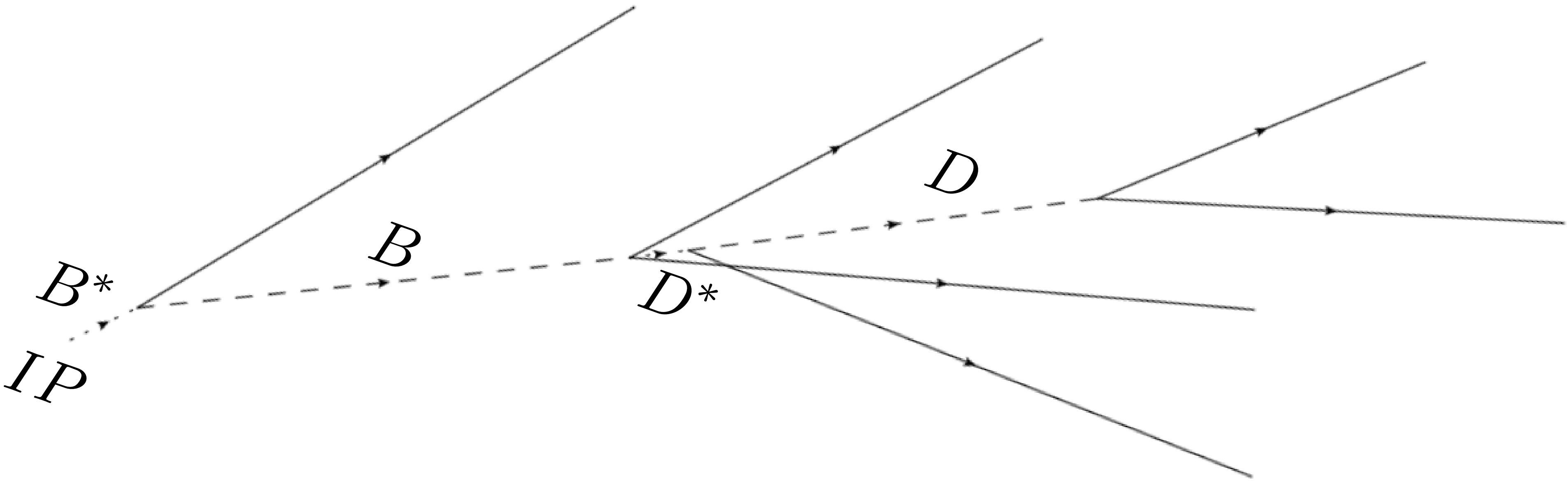
Process overview

- Hadronization of the b-quarks in the MCParticles collection:



Vertex construction

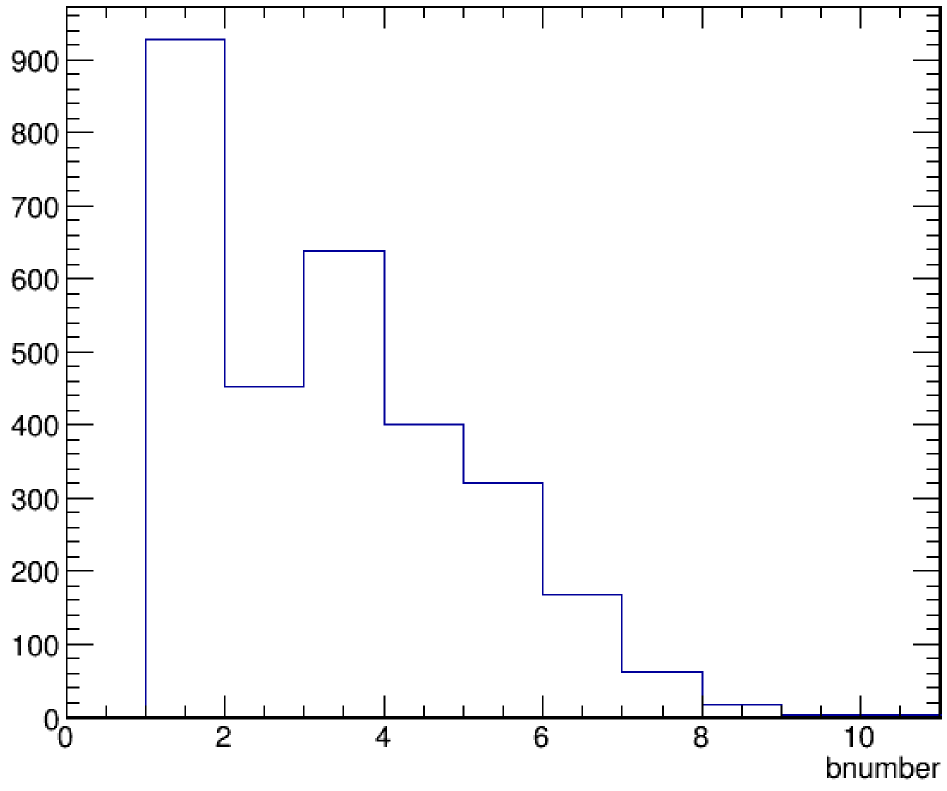
- Decay scheme of the B-hadrons:



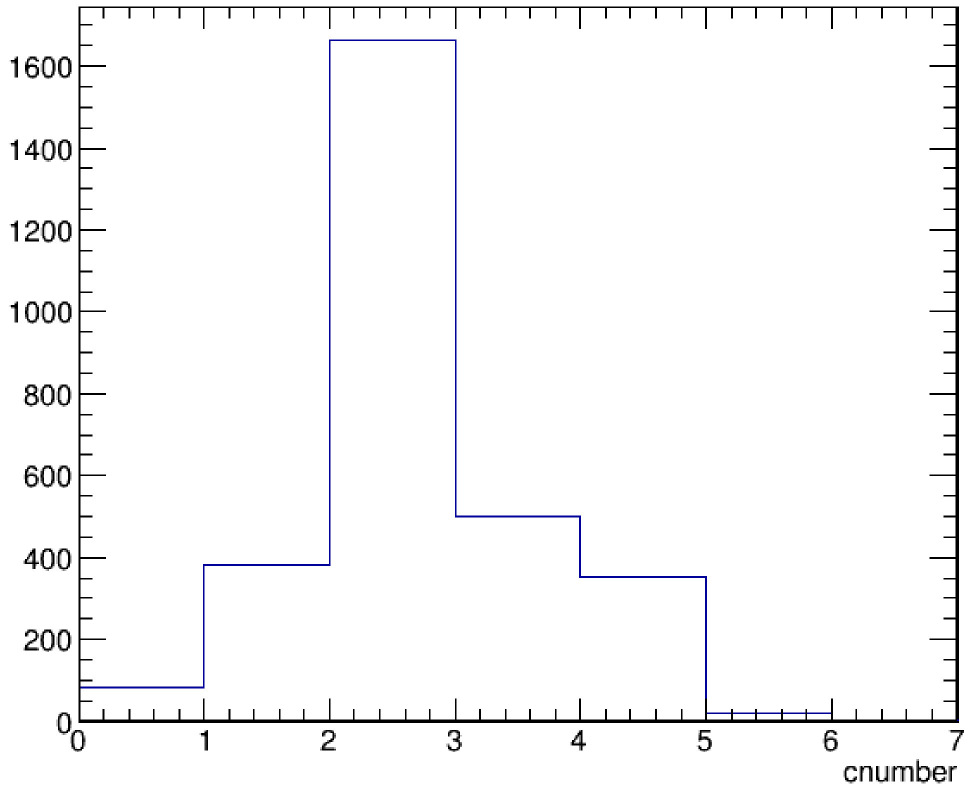
- Excited states of b- and c- hadrons can decay into a charged prong and a ground state hadron
- Decay chain refining procedure selects the last hadron of a given type instead the first one
- A recursive algorithm selects electrons, muons, pions, kaons, protons child particles for each selected hadron to form a secondary and a ternary vertex

Processor output

Secondary vertex

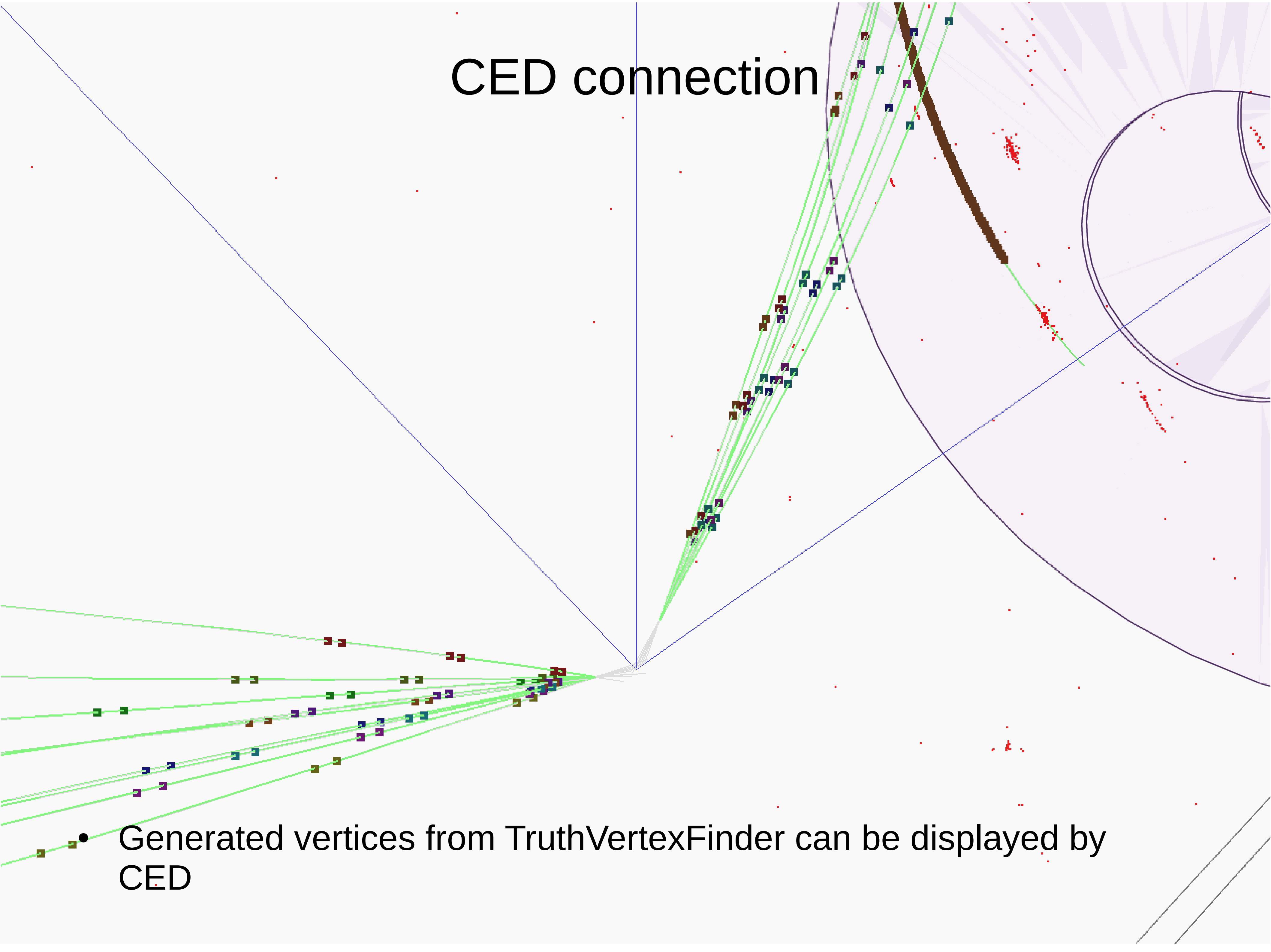


Ternary vertex



- Number of tracks for b and c vertices. For charge measurement the 1-prong decay is dangerous and it is present in both vertices

CED connection



- Generated vertices from TruthVertexFinder can be displayed by CED

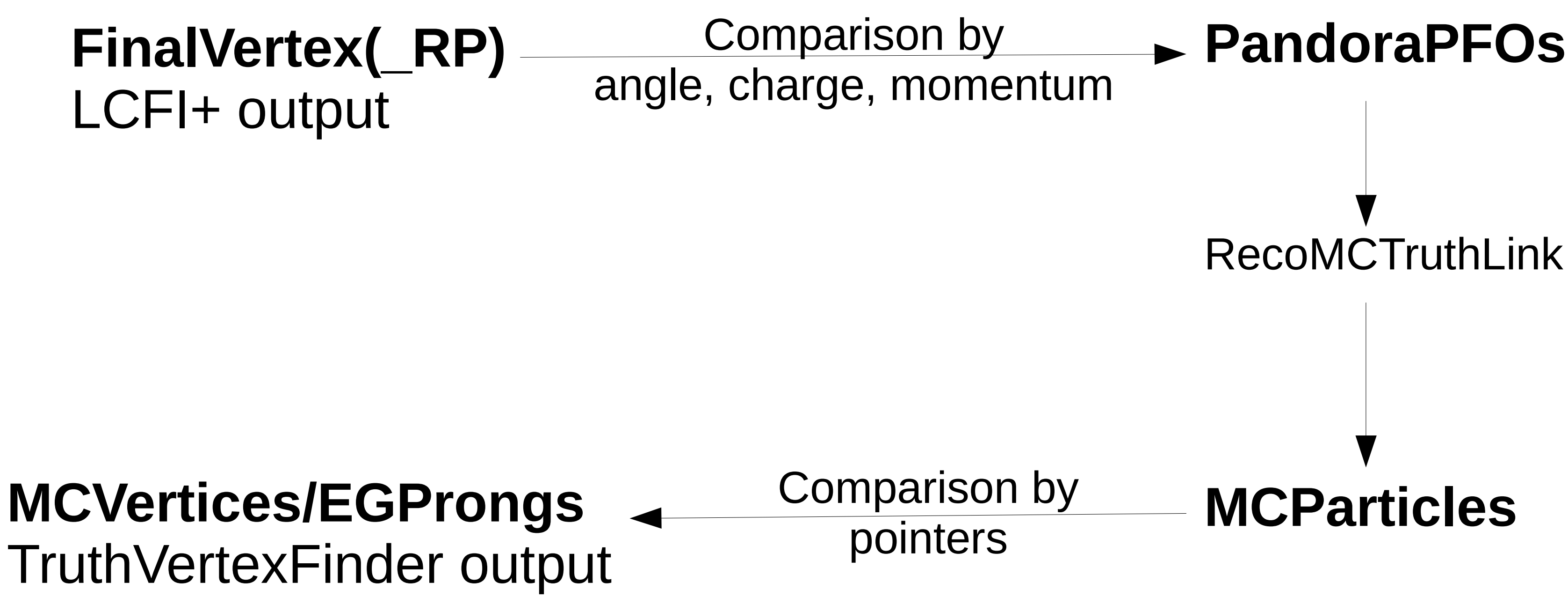
- Introduction
- TruthVertexFinder
- ➔ **Reconstruction validation**
- VertexChargeRecovery

Comparison to reconstruction

- We compare the output of TruthVertexFinder to output collections from LCFI+ JetVertexRefiner algorithm using a private processor
- Jets are tagged by the minimal angle between associated reconstructed vertex and a generated vertex
- Particles from a reconstructed vertex are compared to particles from a corresponding generated vertex
- If a generated vertex is not reconstructed it is marked as “lost”
- All results are written to ROOT TTree

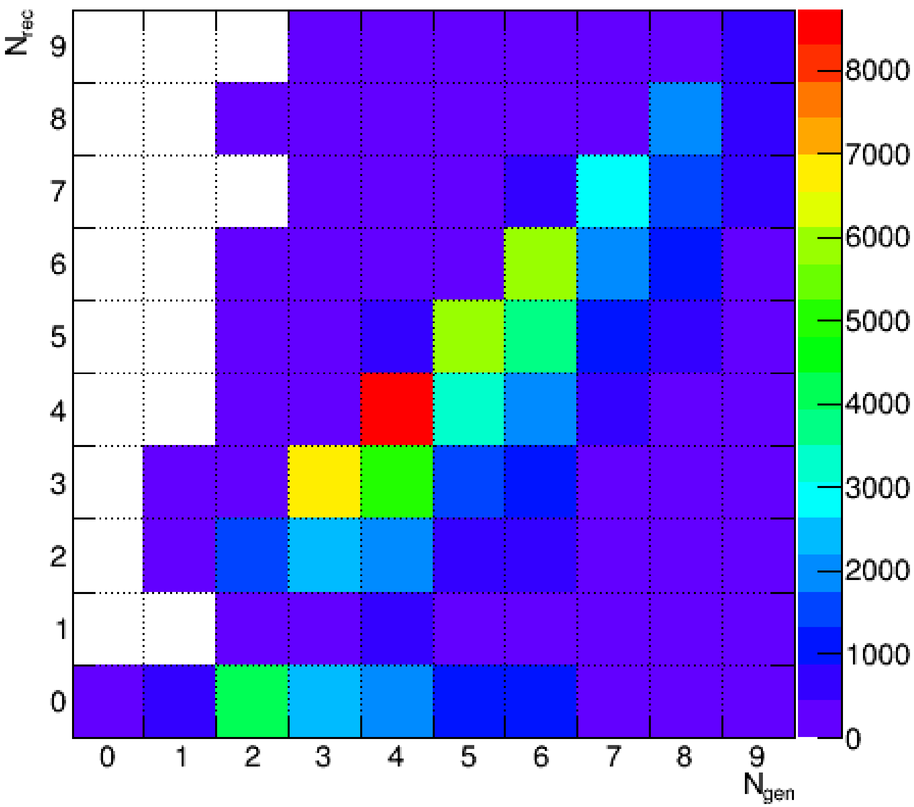
Search for missed tracks

- Main purpose of this processor is to look for the particles from B-meson that are missed in the reconstruction
- Some of the reconstructed secondary particles in LCFI+ output are copied from PandoraPFOs and do not have any RecoMCTruthLink available
- The following scheme allows us to look for a missed particles by using the truthlink:

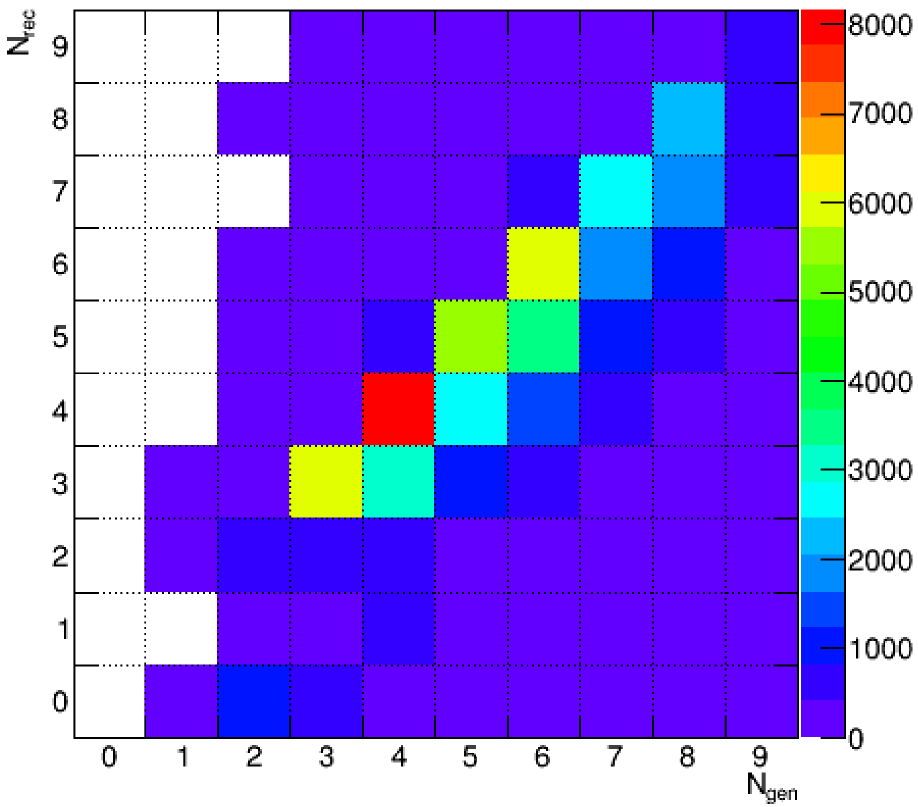


Comparison to reconstruction

Raw



Btag > 0.8 & Pb > 15 GeV



- Vertex reconstruction quality check

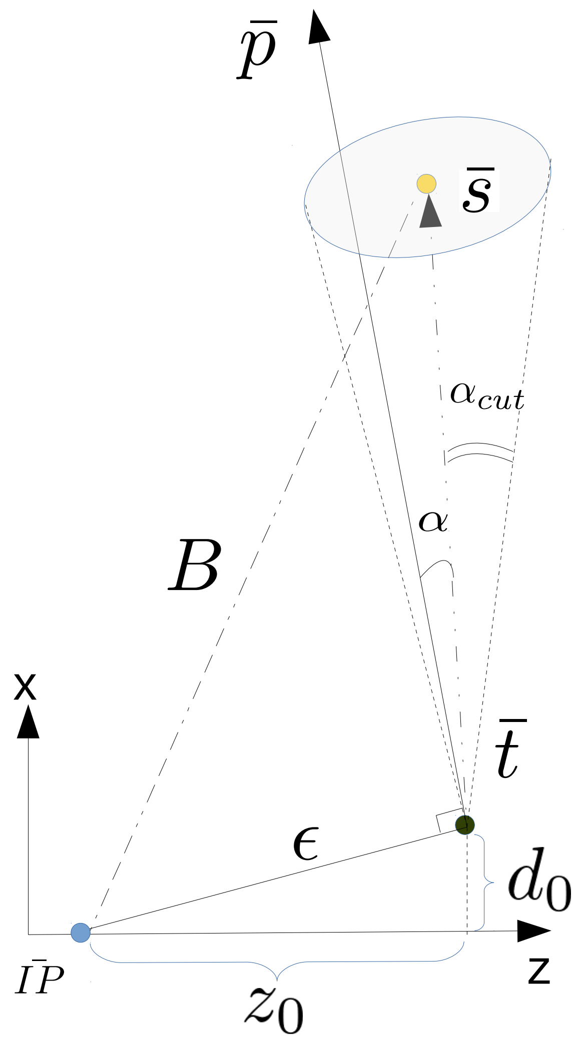
- Introduction
- TruthVertexFinder
- Reconstruction validation
- → **VertexChargeRecovery**

VertexChargeRecovery IO

- Designed to have an identical output to JetVertexRefiner and FlavourTag algorithms from LCFI+
- Input:
  - JetCollectionName (string) – jet collection, Example: FinalJets
  - JetRelCollectionName (string) – jet-vertex relation collection, Example: FinalJets_rel
  - SecondaryCollectionName (string) – vertex collection. Example: FinalJets_vtx
  - NotUsedTracksCollectionName (string) – collection of tracks that were not used to create PFOs, Example: TracksFailBothCanFormPfoFlags – for REC files

    MarlinTrkTracks – for DST files
  - UseTracks (bool) – flag to use non-PFO tracks or not
- Output:
  - Similar output LCIO collections as the input ones, RecoveredJets, RecoveredJets_rel, RecoveredJets_vtx ...

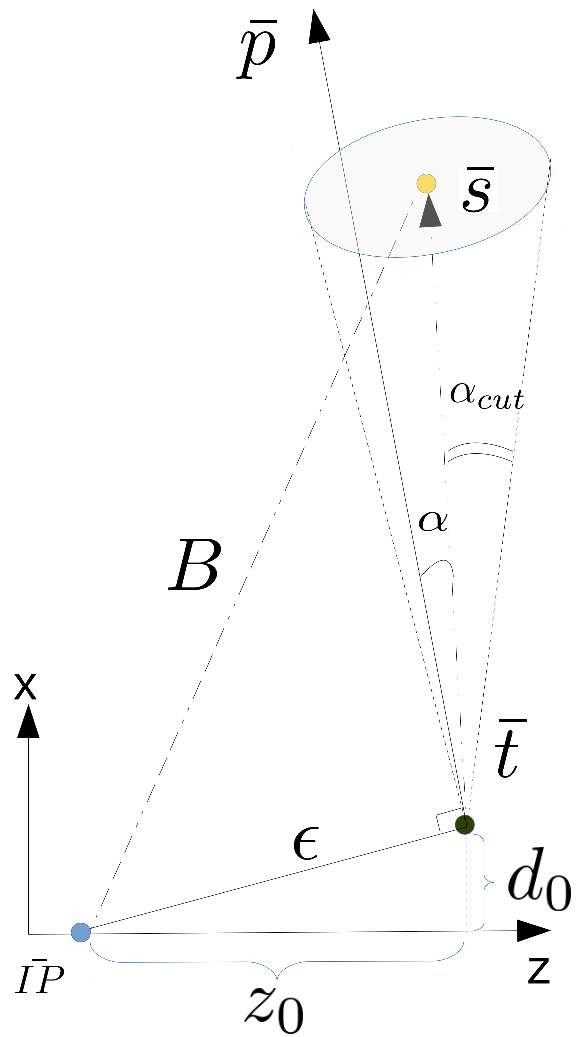
Recovery of the vertices

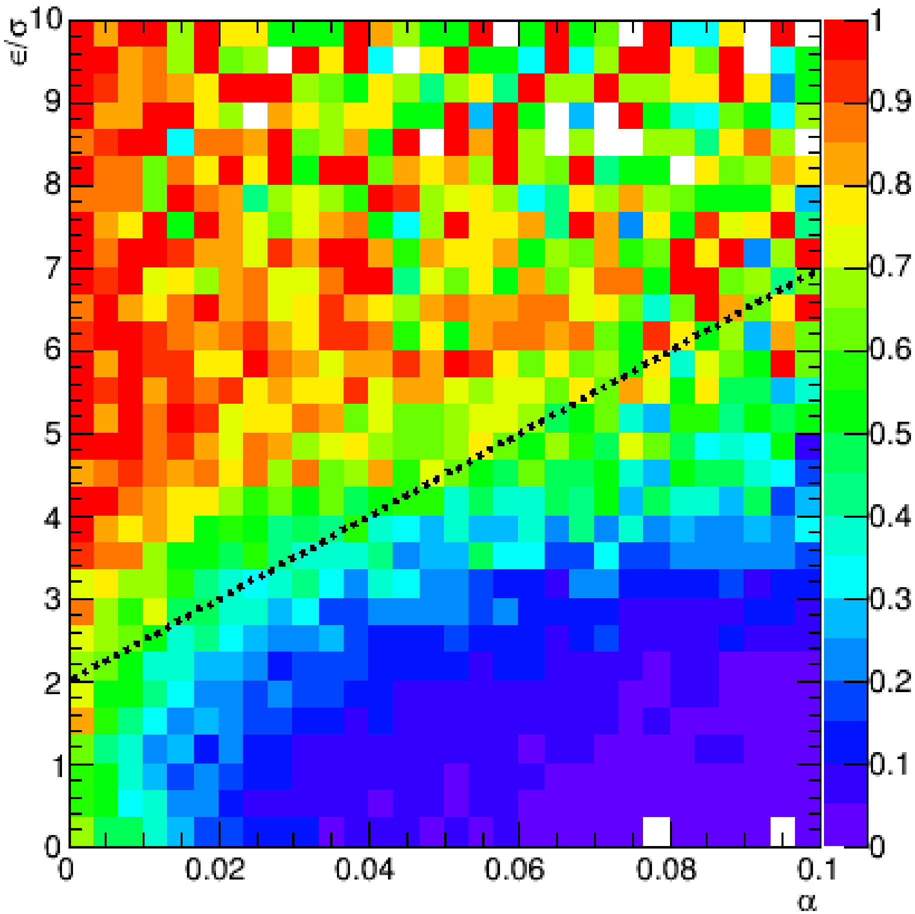


- For each reconstructed vertex we check if a particle from the same jet is compatible with the vertex
- New vertex object is constructed using new particles
- New LCRelation object connects the recovered vertex with corresponding jet object

- **IP** – interaction point (primary vertex) , **s** – secondary vertex, **t** – point of closest approach of a track, **p** – reconstructed momentum, ϵ - offset of a track from primary vertex

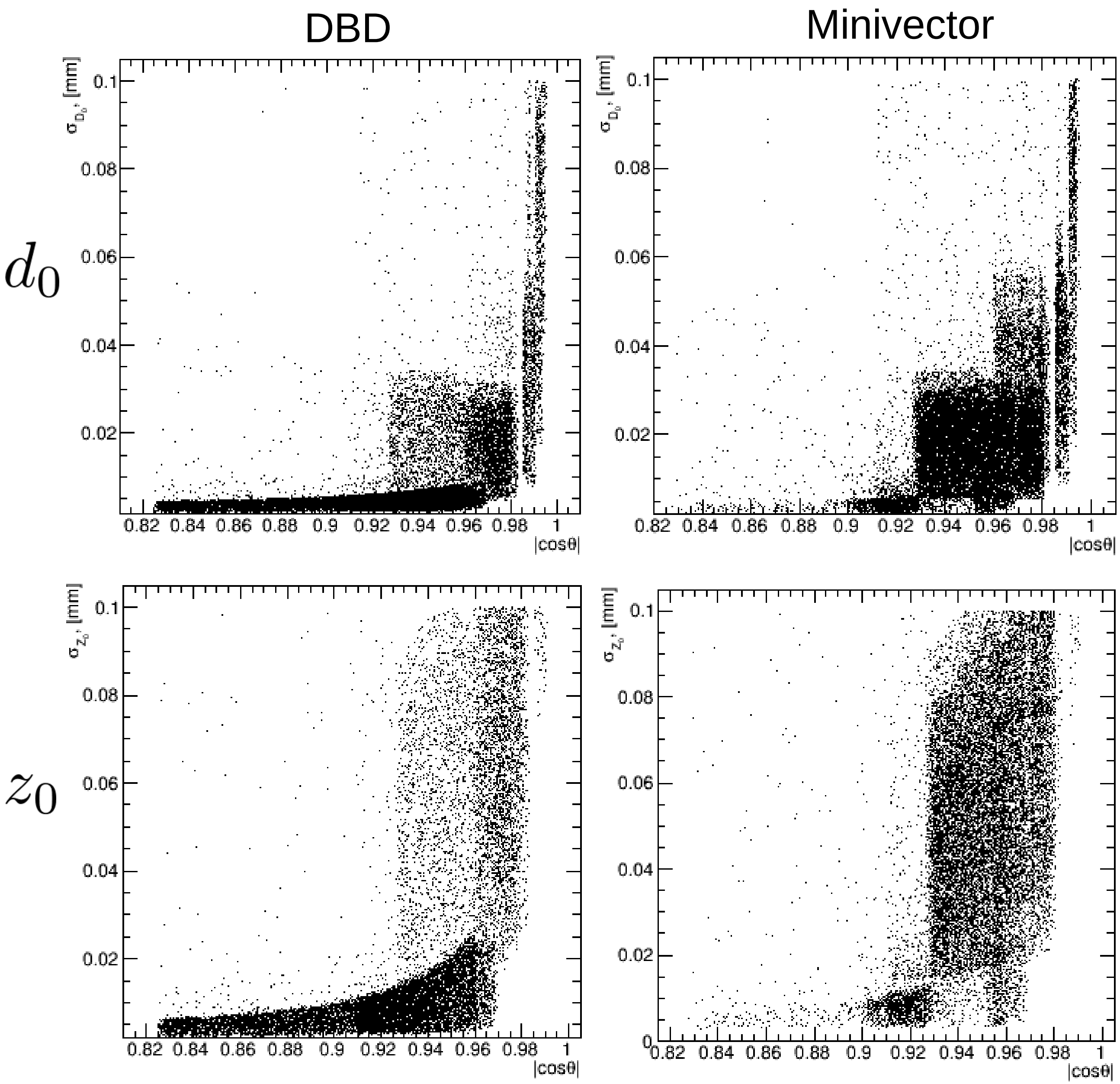
Recovery of the vertices





- **IP** – interaction point (primary vertex) , **s** – secondary vertex, **t** – point of closest approach of a track, **p** – reconstructed momentum, ϵ - offset of a track from primary vertex $\epsilon/\sigma = d_0/\sigma_{d_0} + z_0/\sigma_{z_0}$

Track parameter uncertainties



- Angular distribution of d0 and z0 uncertainties for DBD and minivector (CellsAutomatonMV) tracking.
- The transition to the forward region is puzzling
- Minivector has a step-function-like uncertainty behavior

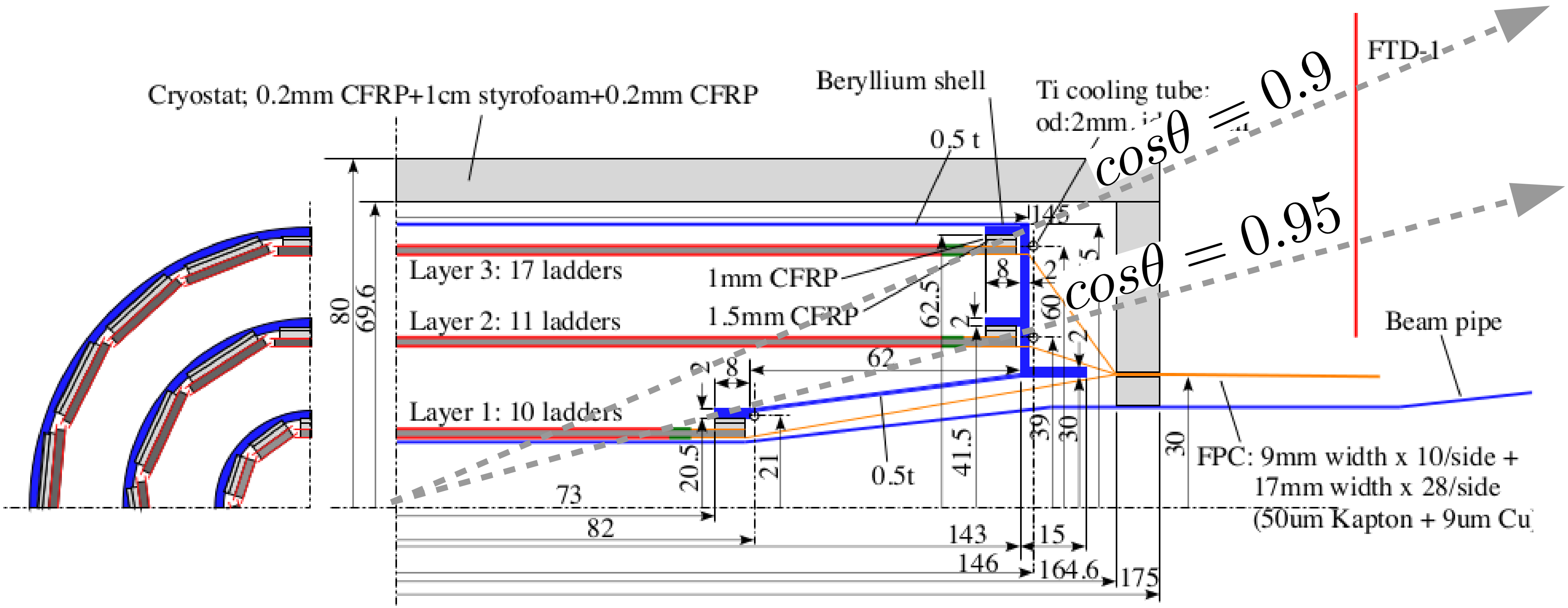
P > 10 GeV & FTD hits > 1

Summary

- We developed a complete software framework to study for vertex charge measurement
- Vertex charge recovery requires combination of different sources of information, including non-standard reconstruction
- May need better understanding of barrel to forward region transition
- Methods are designed to work on ttbar process at ILC
  - Can be extended to bbbar process

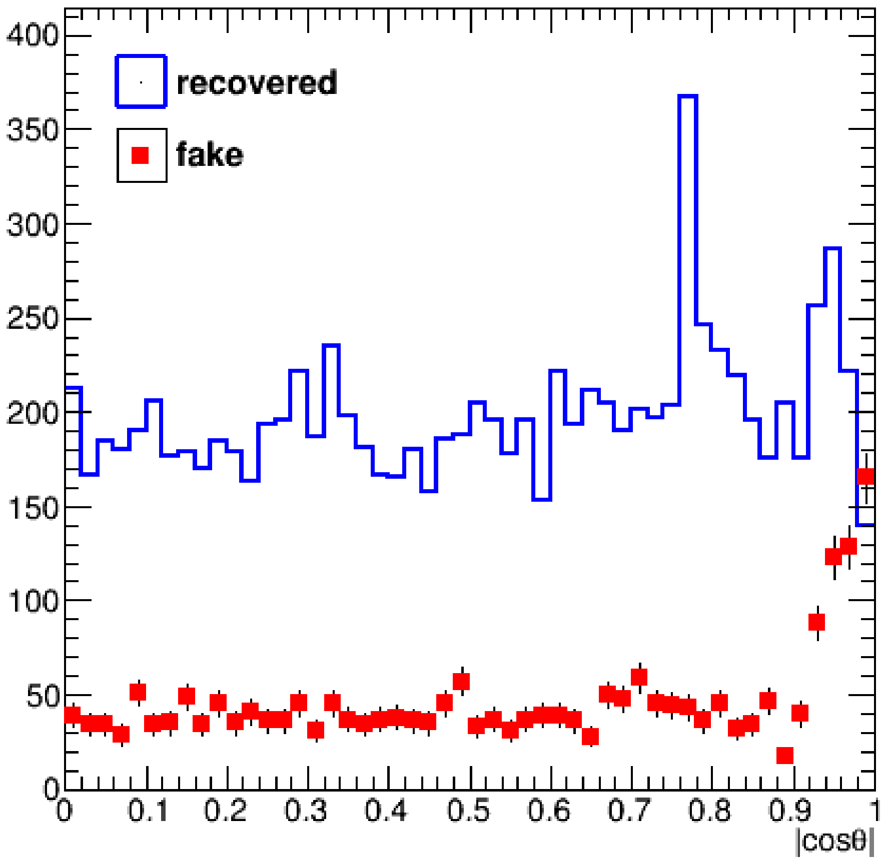
Thank you!

Directions in ILD

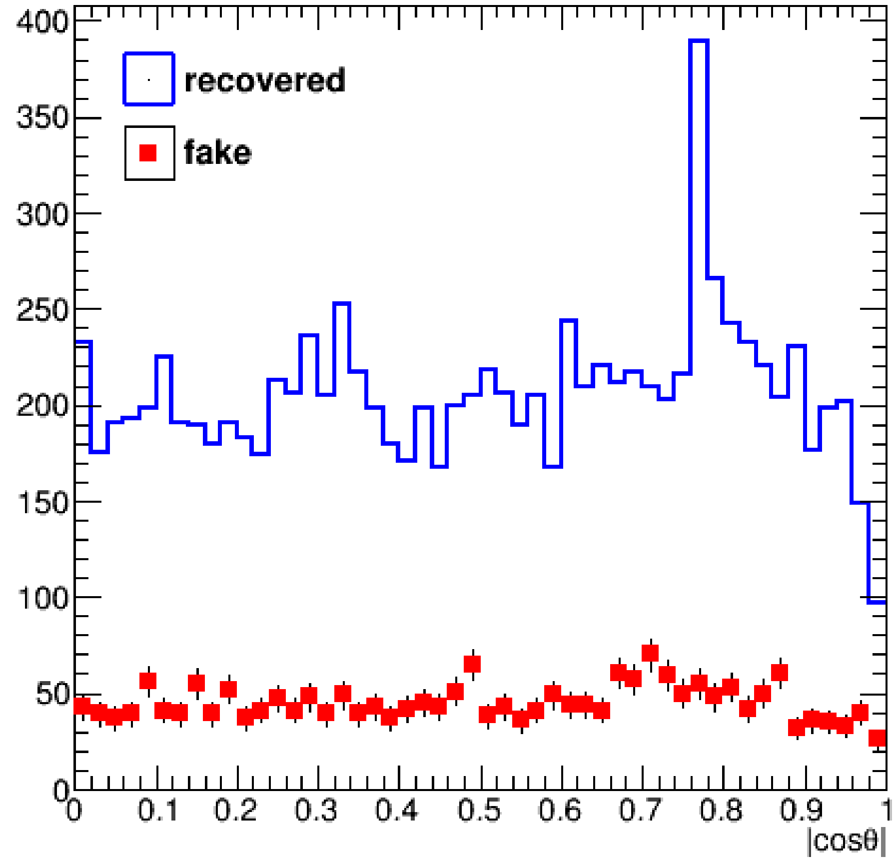


Old offset vs new offset

$$\frac{\varepsilon}{\sigma_{\epsilon}}$$

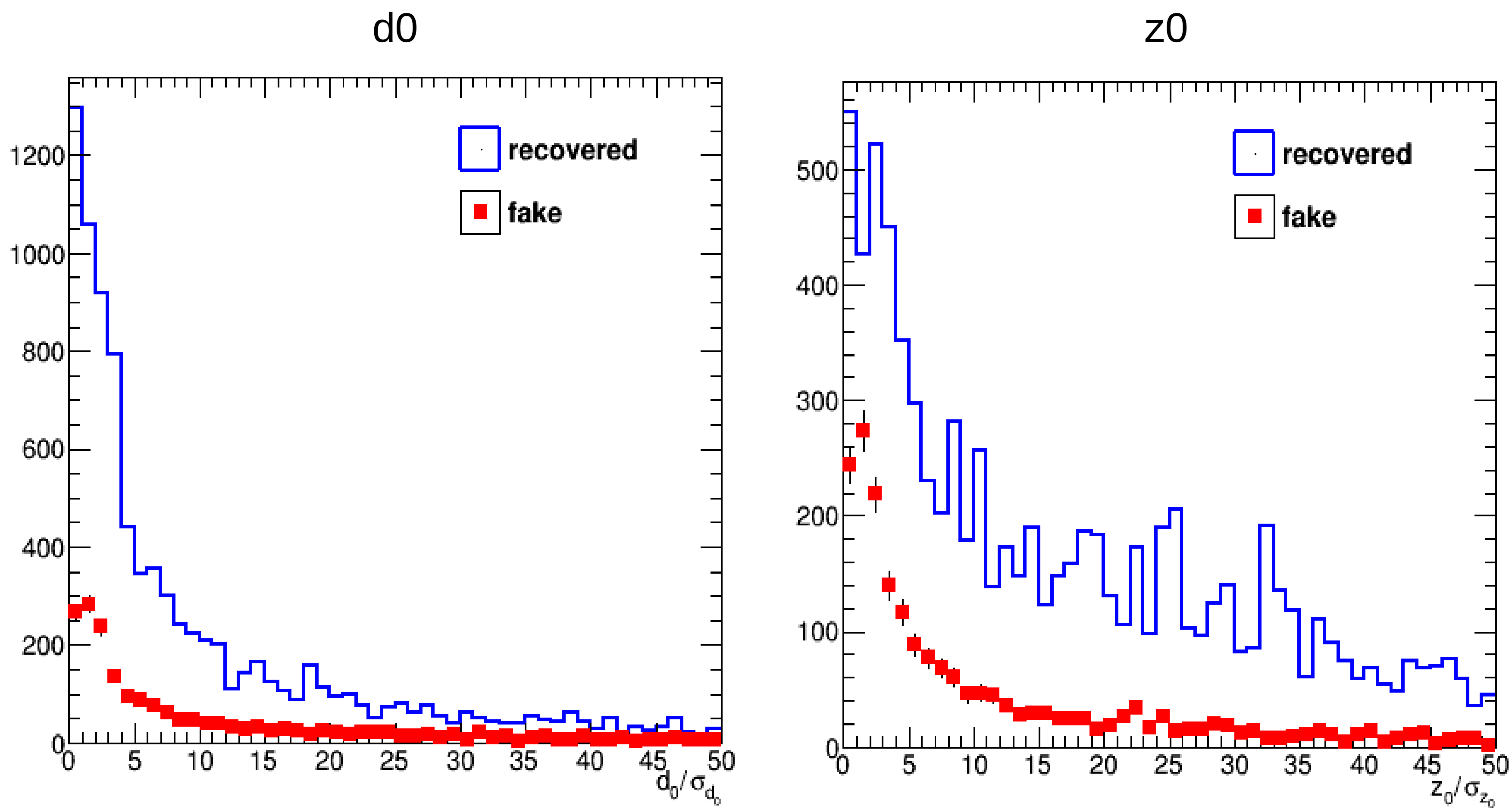


$$|\frac{d_0}{\sigma_{d_0}}| + |\frac{z_0}{\sigma_{z_0}}|$$



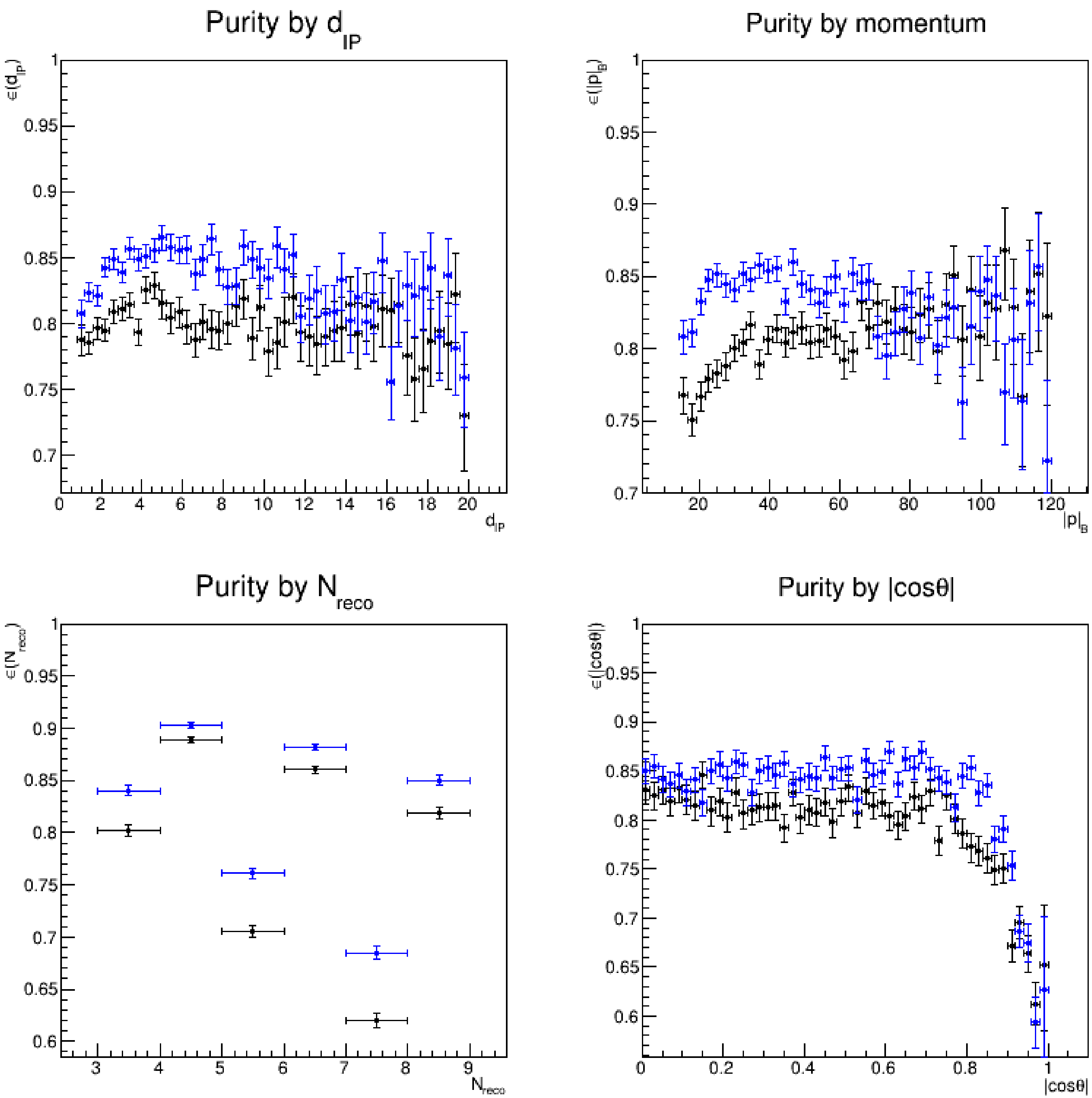
- Angular distribution of the recovered b-tracks and background (fake) tracks. Minivector tracking.

Components of the offset significance



- Components of the offset significance.

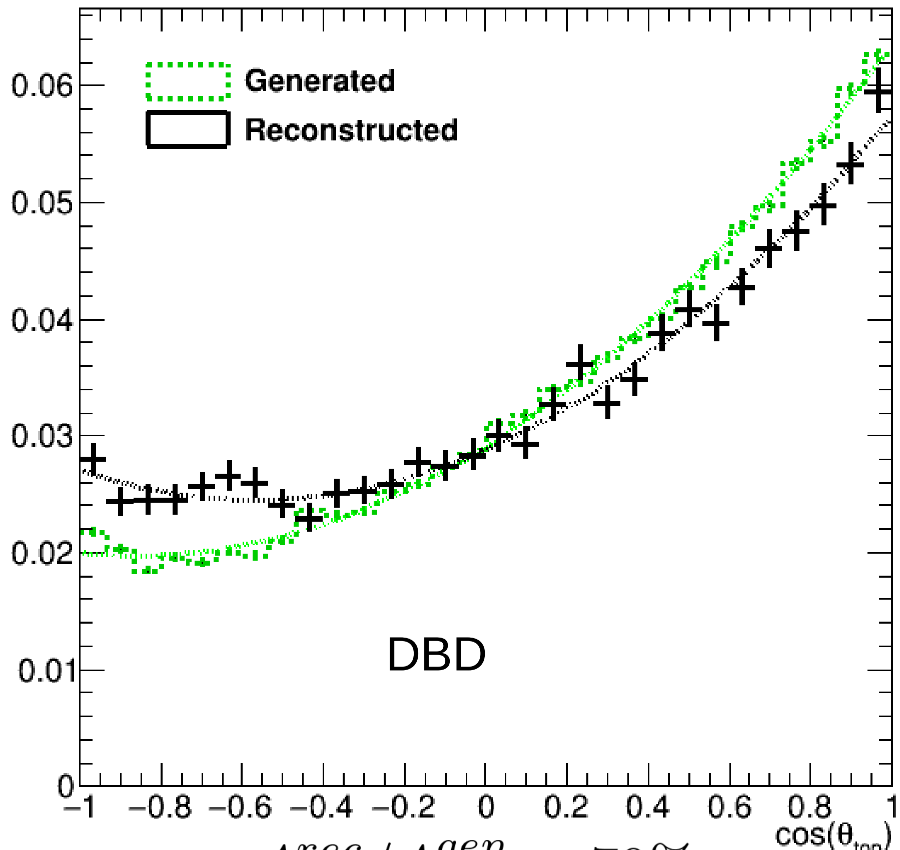
Overall charge purity improvement



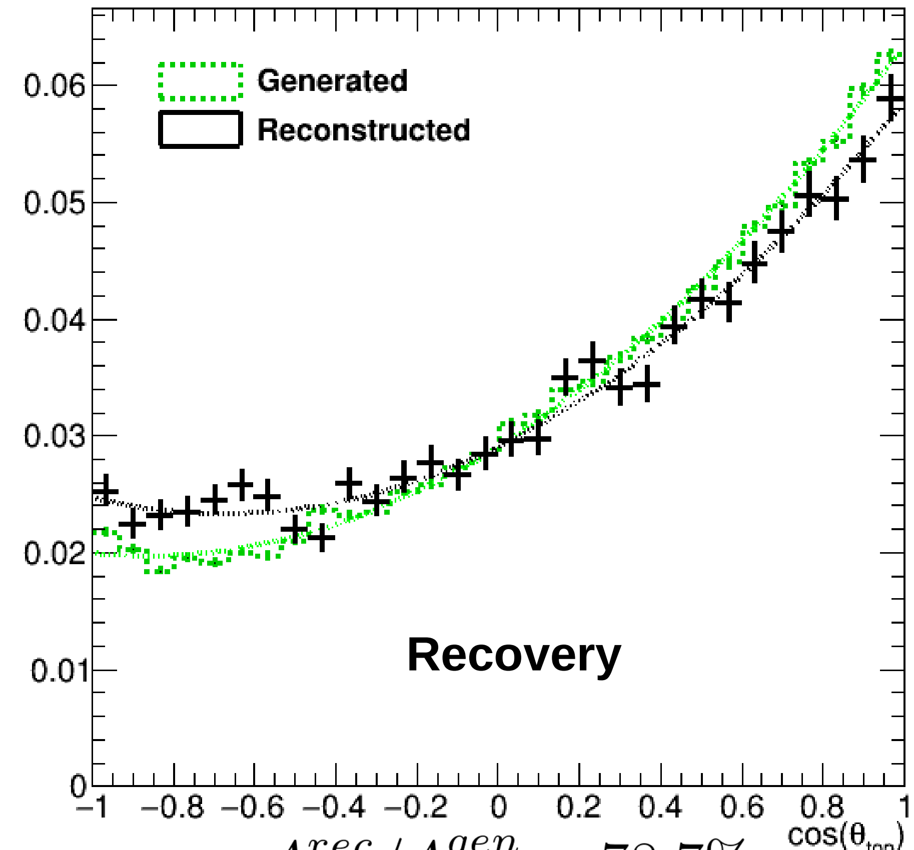
Minivector + recovery
DBD+recovery

- B-meson charge purity as a function of different parameters.
- Minivector sample has ~3% larger purity

DBD top polar angle reconstruction



$A_{fb}^{rec}/A_{fb}^{gen} = 70\%$

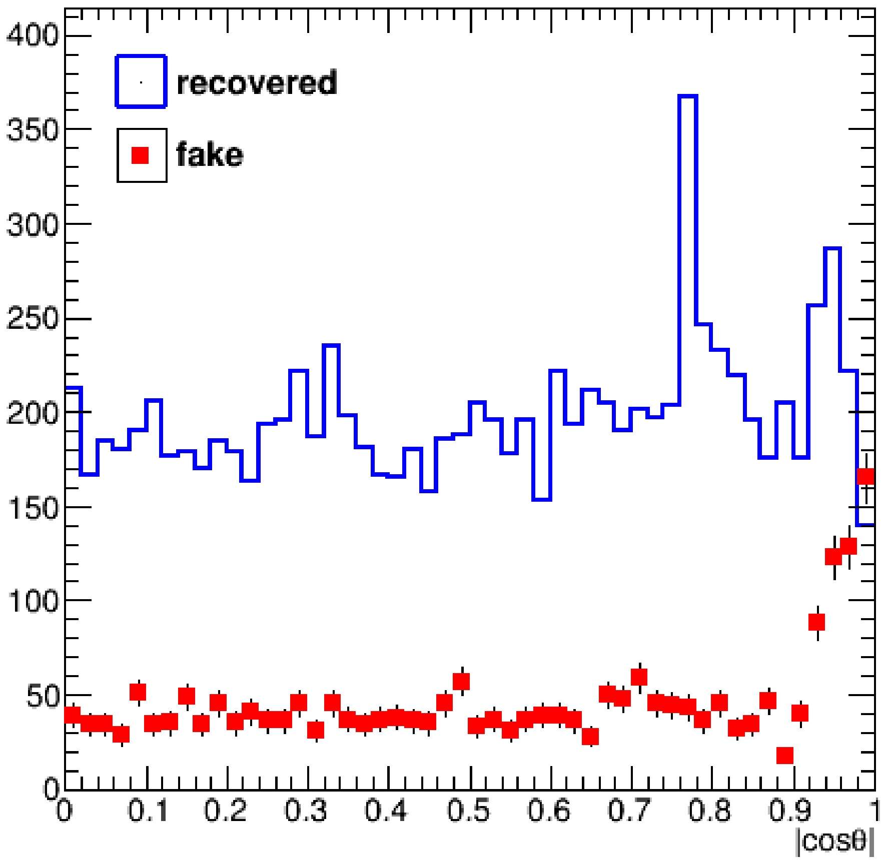


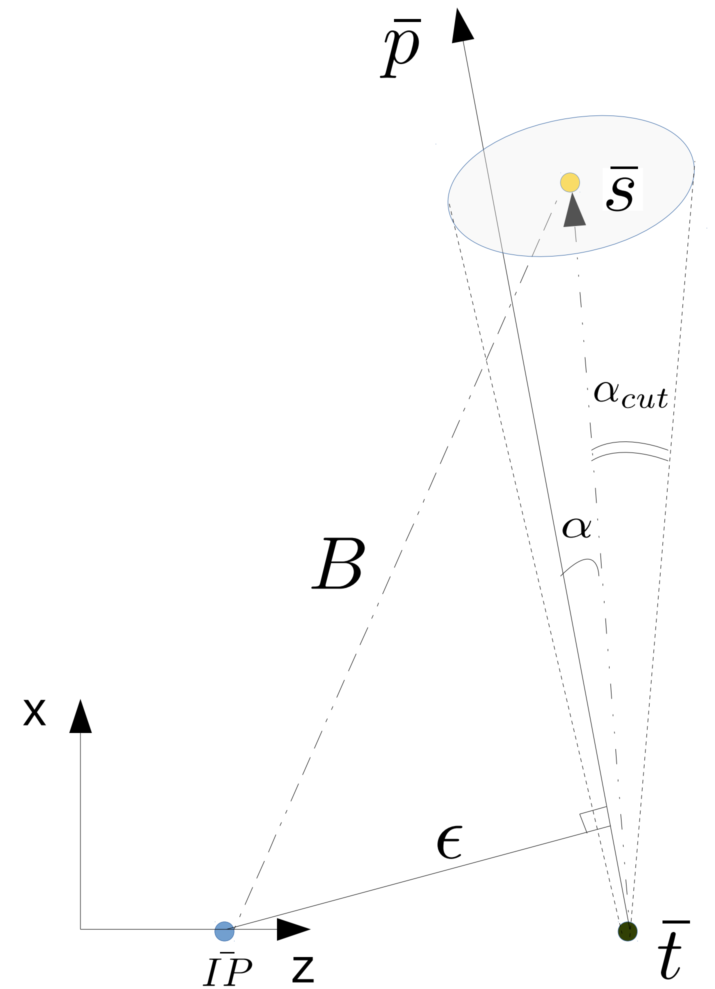
$A_{fb}^{rec}/A_{fb}^{gen} = 78.7\%$

- Top polar angle reconstruction for DBD and DBD + new recovery for vertex charge only.

Recovery optimization

$$\frac{\varepsilon}{\sigma_\epsilon}$$

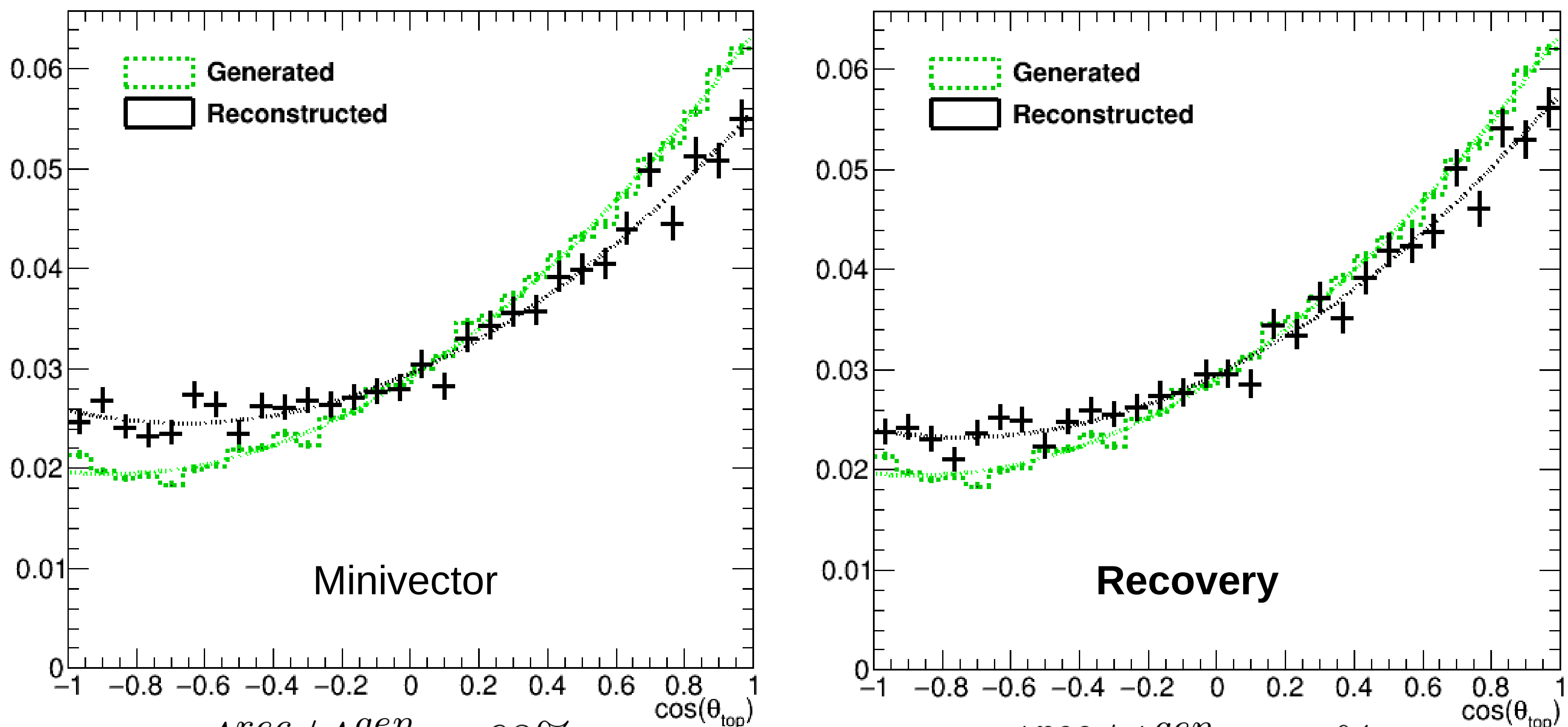




$$\varepsilon/\sigma_\varepsilon > 2.0 + 50 * \alpha$$

- Angular distribution of the recovered b-tracks and background (fake) tracks. Covariance matrix is used. Minivector tracking.

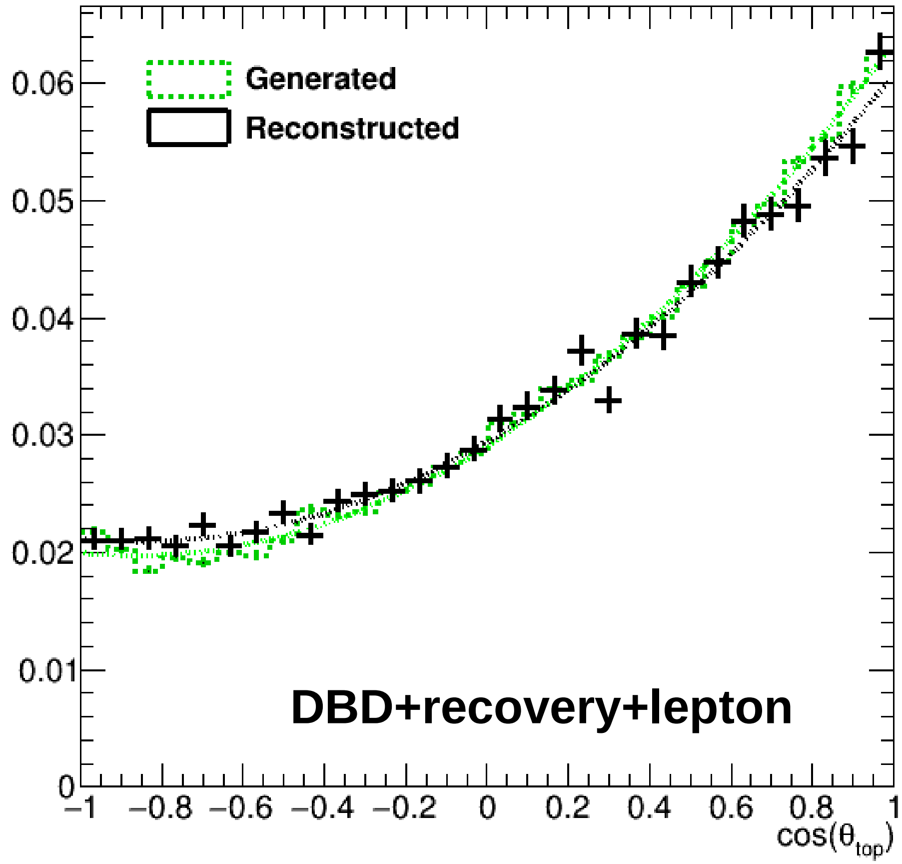
Minivector top polar angle reconstruction



$A_{fb}^{rec}/A_{fb}^{gen} = 68\%$ $A_{fb}^{rec}/A_{fb}^{gen} = 75\%$

- Top polar angle reconstruction for Minivector and Minivector + new recovery. Efficiency and purity is lower than for DBD tracking
- LeptonFinder and flavour tagging are not optimized for minivector tracking

Improvement by W leptonic



$A_{fb}^{rec}/A_{fb}^{gen} = 92.7\%$

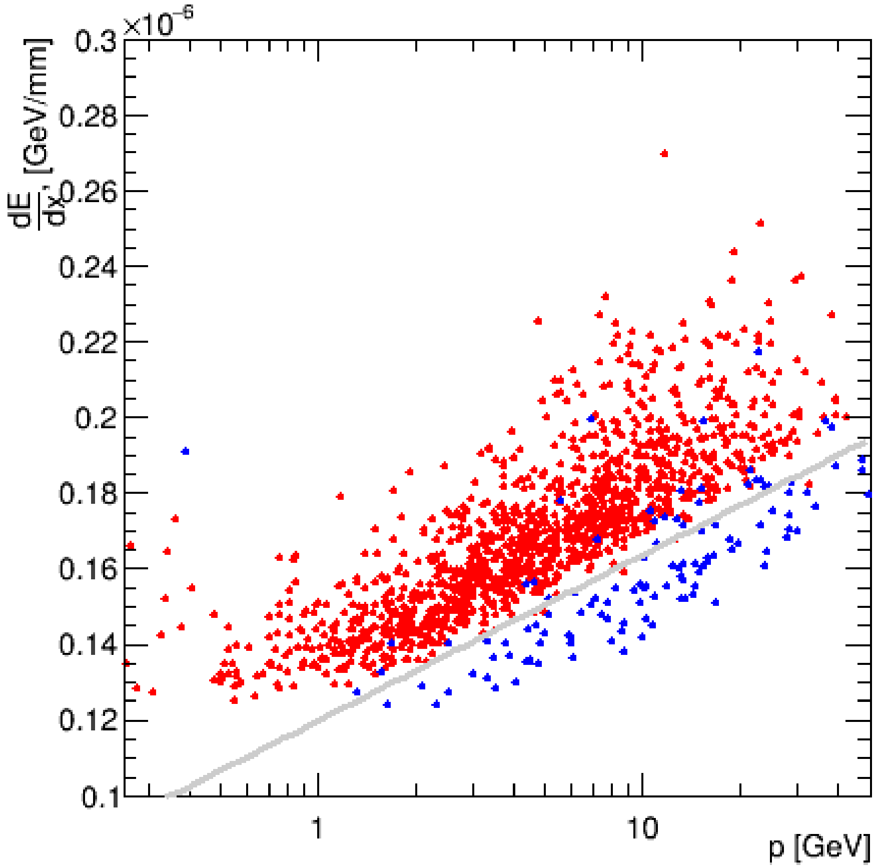
~40% efficiency

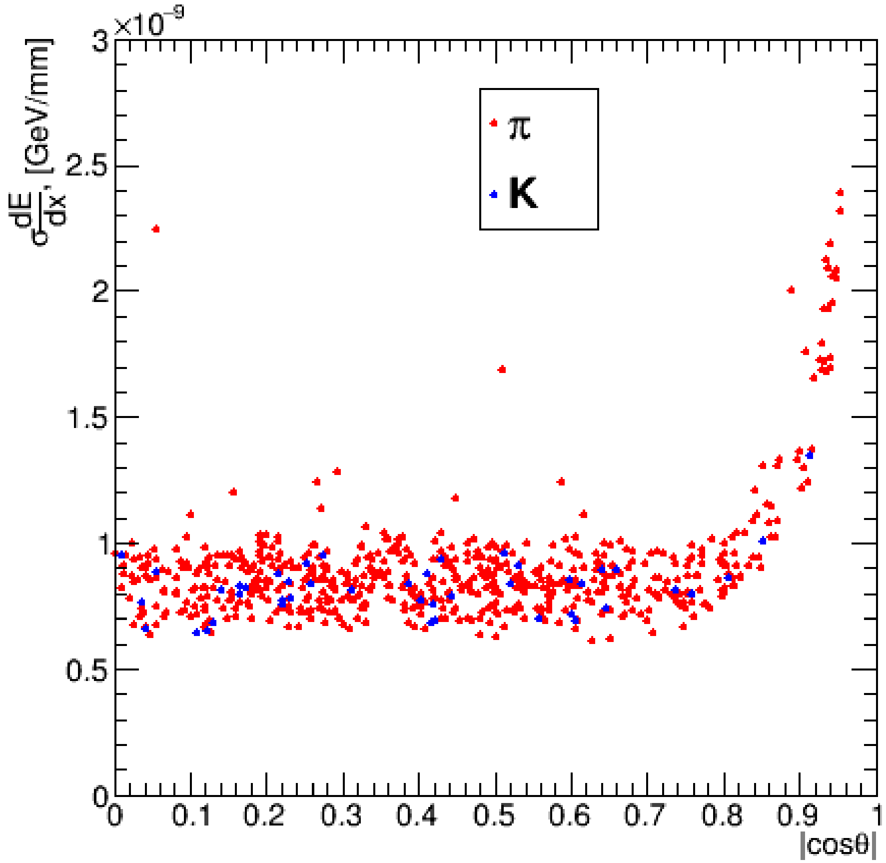
- The events are selected if there is a non-contradicting B-jet charge and lepton charge from W or $\chi_t^2 < 15$
- The efficiency of this method is ~10% higher than published result [arXiv:1307.8102 [hep-ex]]

- Top polar angle reconstruction for DBD using combination with lepton charge from W decay.

$$\chi_t^2 = (\frac{m_{rec} - m_t}{\sigma_m})^2 + (\frac{E_{rec} - E_{beam}}{\sigma_E})^2 + (\frac{p^*_{rec} - p^*_b}{\sigma^*_p})^2 + (\frac{cos\theta_{rec} - cos\theta_{bW}}{\sigma_{cos\theta_{bW}}})^2$$

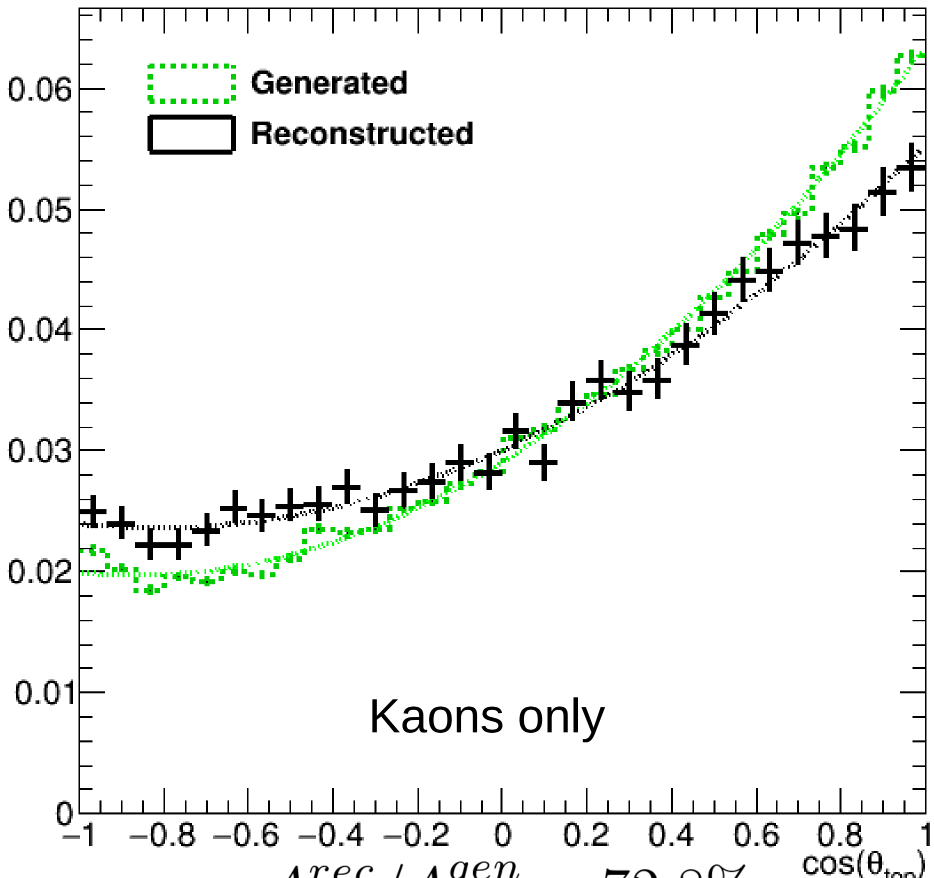
Kaon identification



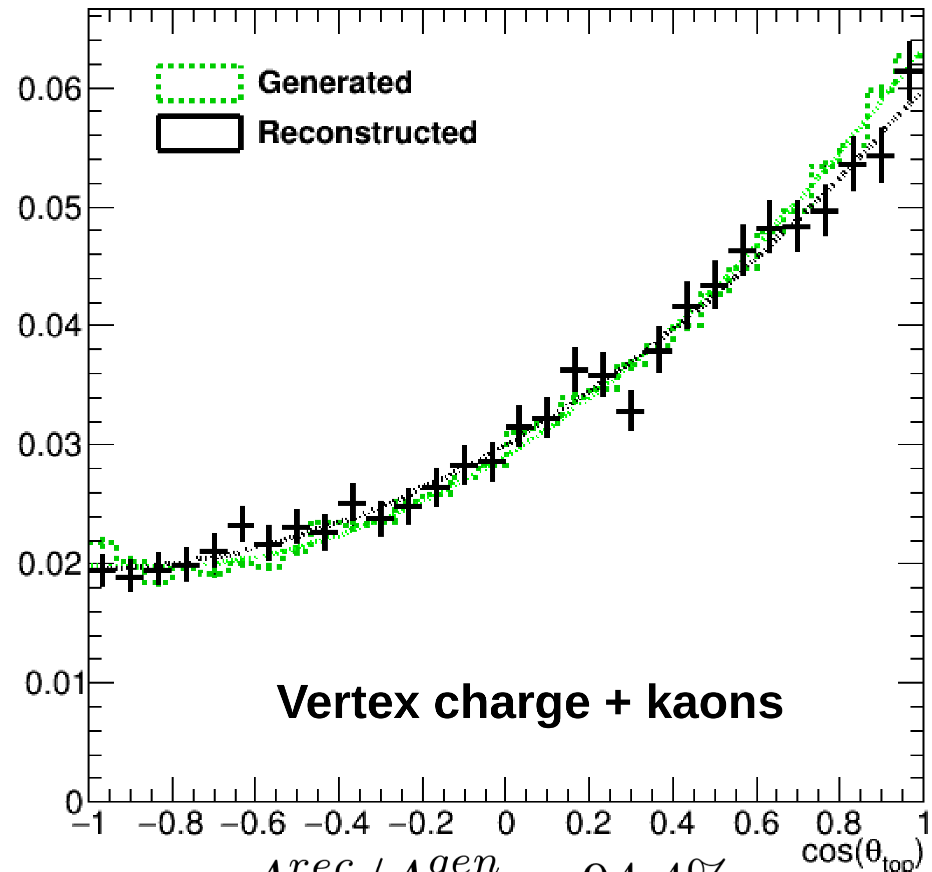


- Kaon-pion separation in dE/dx measurement taken from PIDTools for all secondary and ternary tracks
- In current analysis kaons are selected using generator information for ternary tracks with TPC hits > 60 and $|cos\theta| < 0.95$

Improvement by kaons



$$A_{fb}^{rec}/A_{fb}^{gen} = 72.8\%$$



$$A_{fb}^{rec}/A_{fb}^{gen} = 94.4\%$$

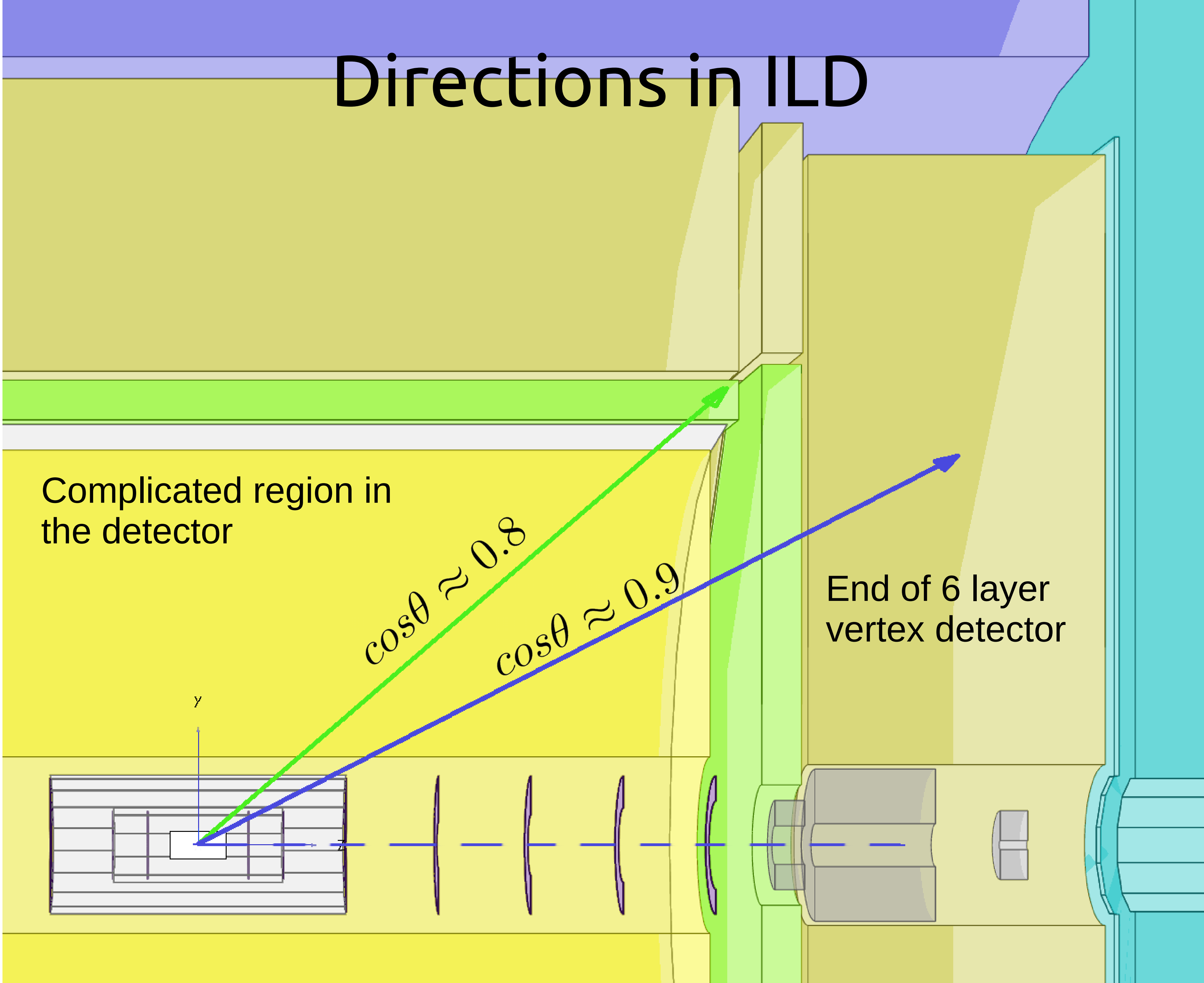
~15% efficiency

- Top polar angle reconstruction using kaons and vertex charge combination. Kaons are identified using generator information for TPC tracks. **B-jet information only.**

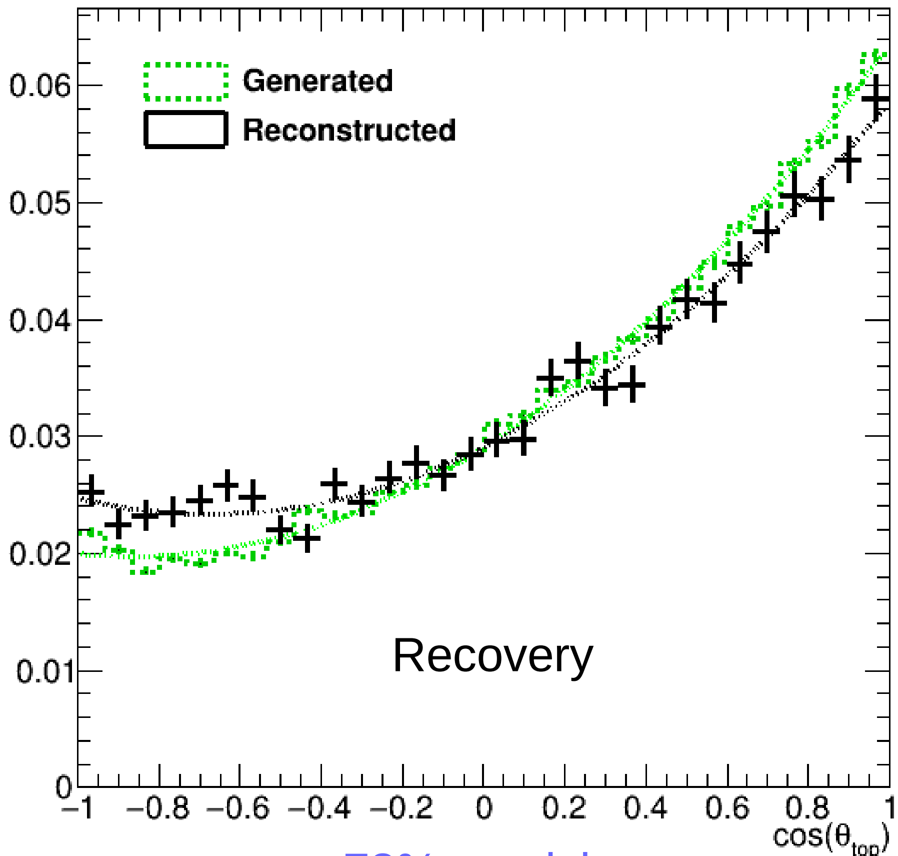
Research setup

- We are using 500 GeV semileptonic ttbar sample eLpR with pair background v01-16-05 (DBD)
- Same sample using CellsAutomatonMV as tracking algorithm v01-17-09 (Minivector)
- TruthVertexFinder from MarlinReco/Analysis to get the generated vertices
- Modified version of VertexChargeRecovery from MarlinReco/Analysis (Recovery)

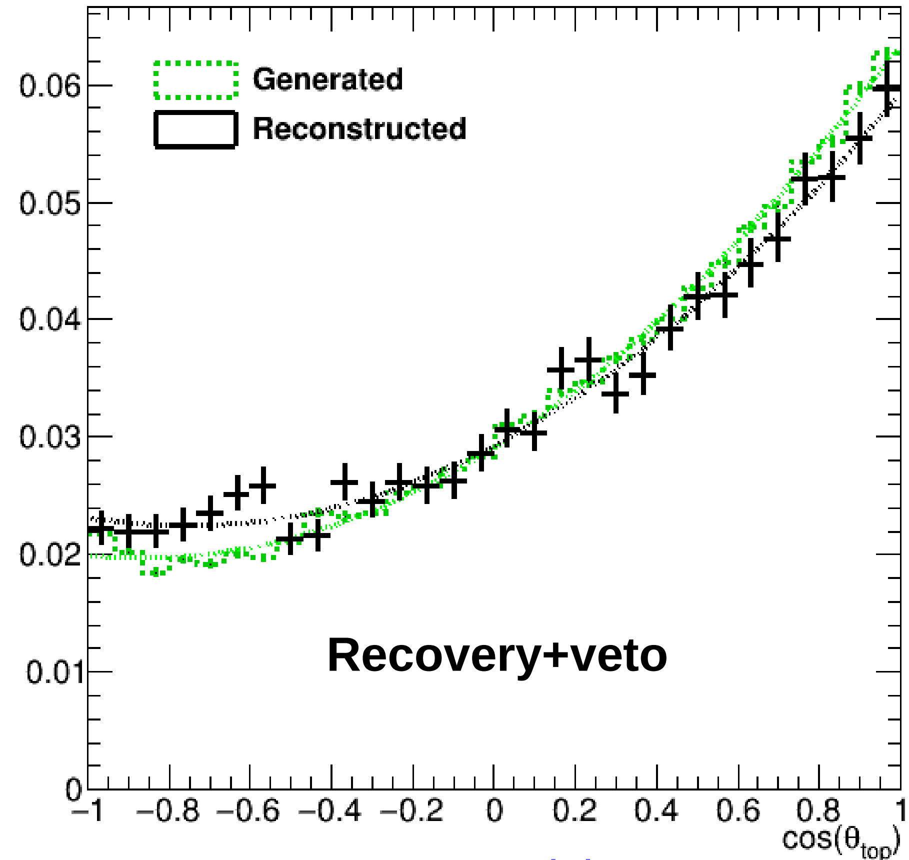
Directions in ILD



Overall top polar angle improvement



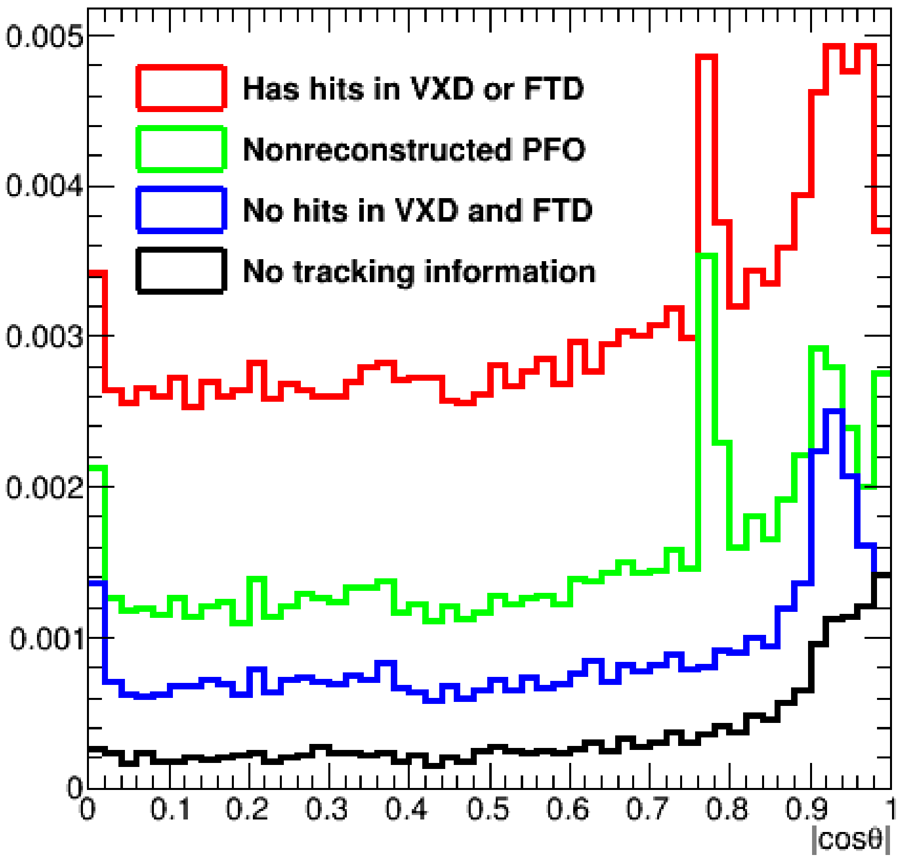
78% precision

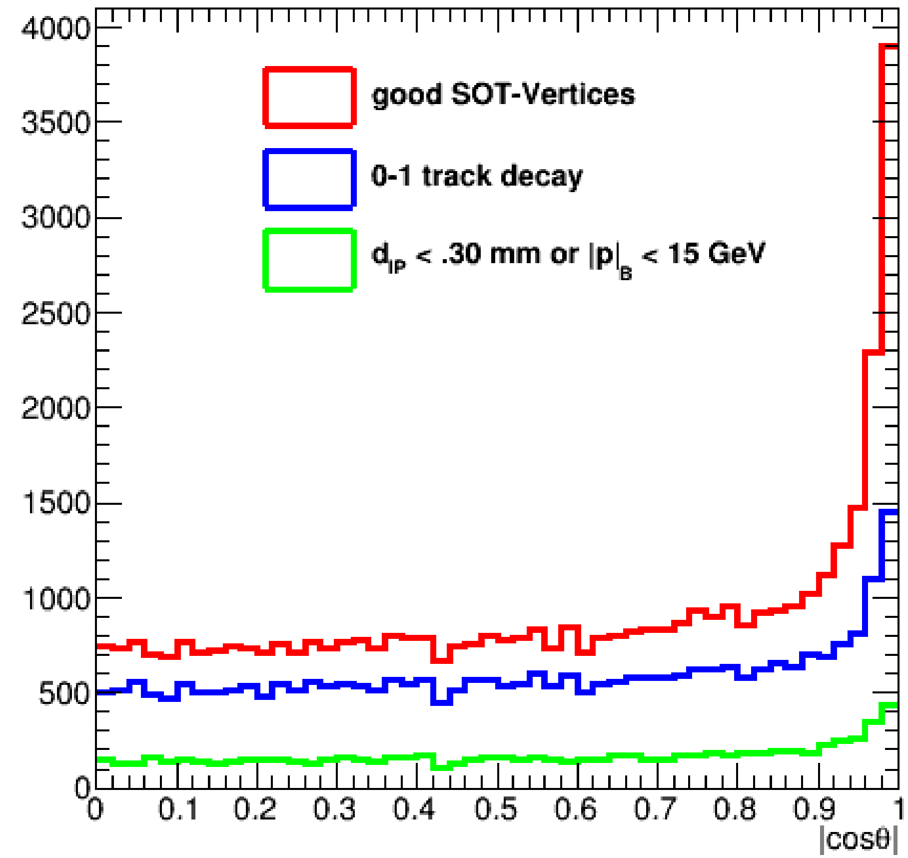


83.7% precision

- Top polar angle reconstruction for DBD. Veto: The DDbar events are excluded using generator information

Missed tracks and missed vertices

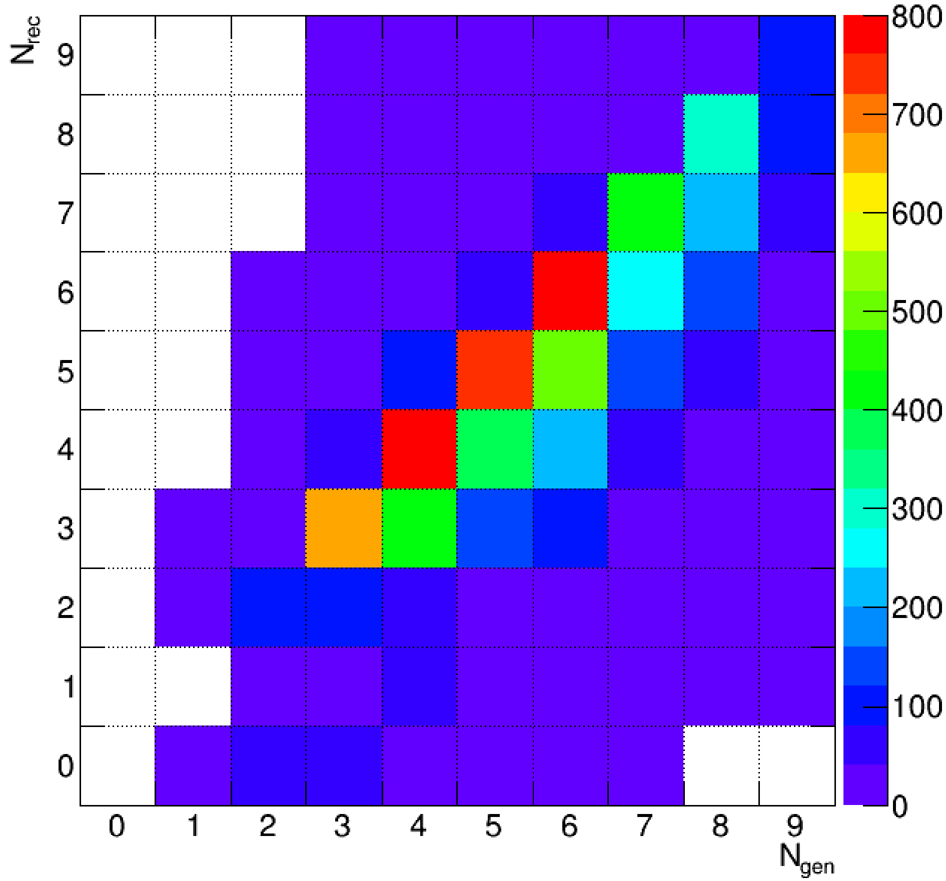




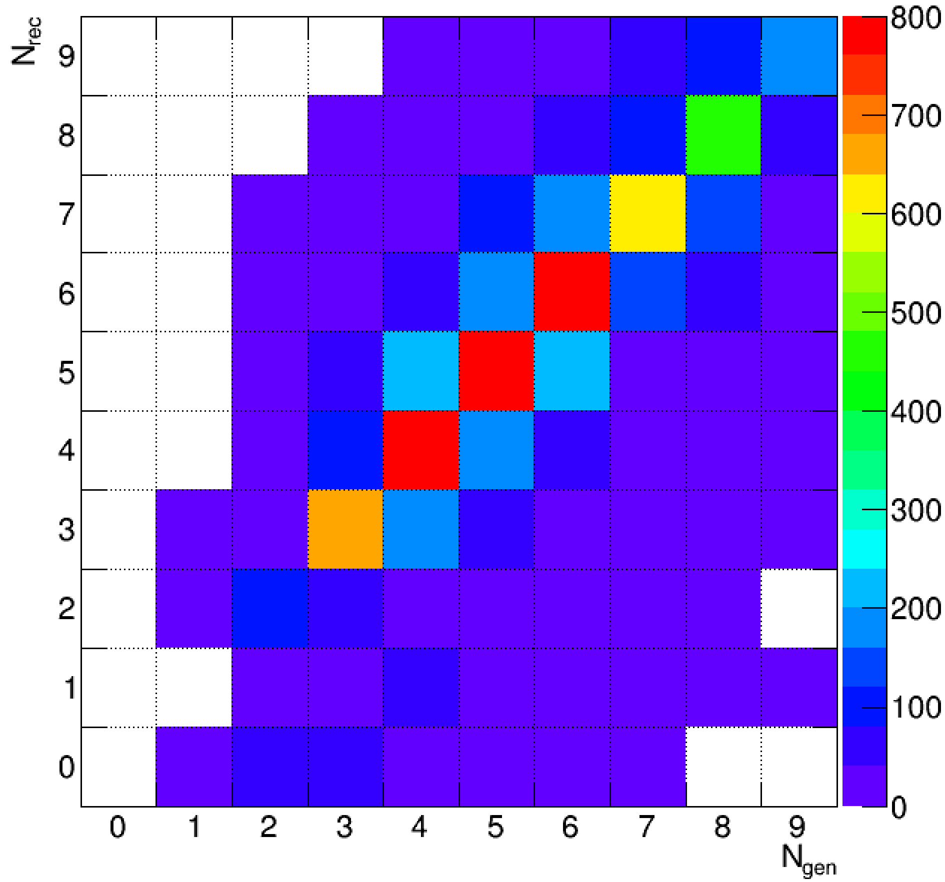
- Angular distribution of the missed tracks from reconstructed vertices.

Number of tracks comparison Minivector

Original



Recovery

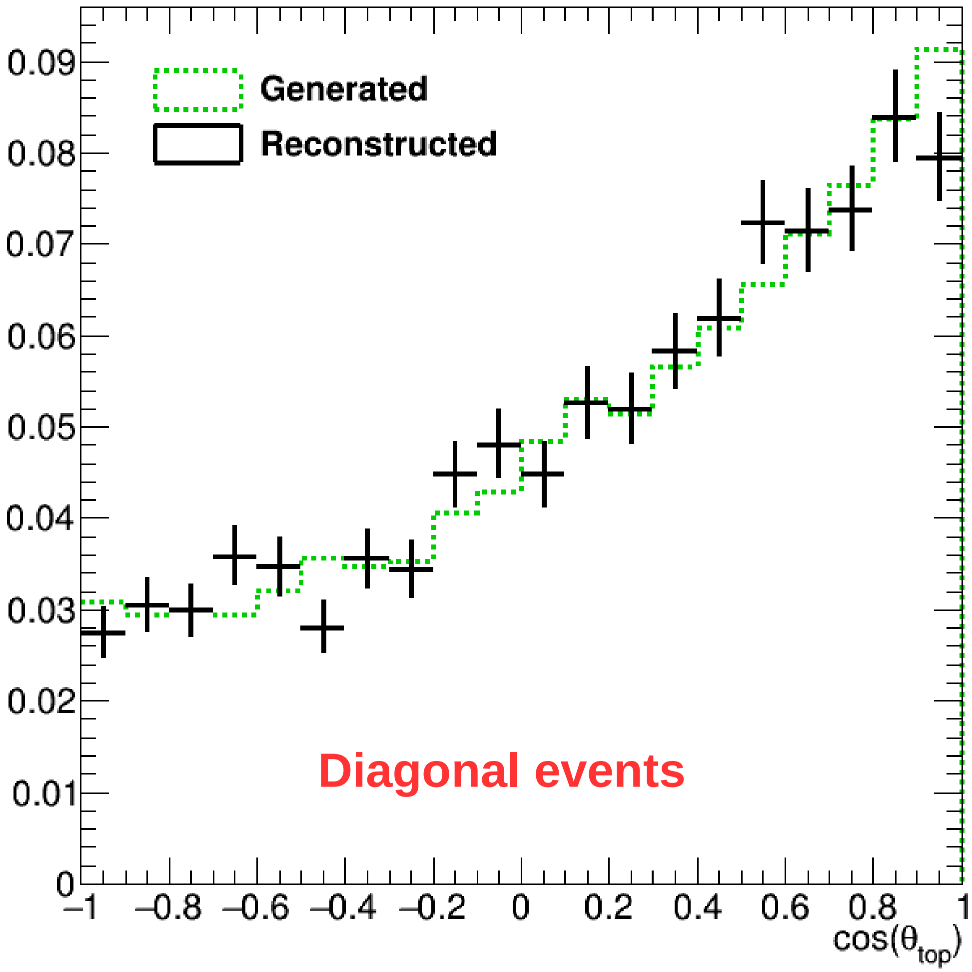


51.0% on diagonal

63.3% on diagonal

Btag > 0.8 & Pb > 15 GeV

Top asymmetry: diagonal events

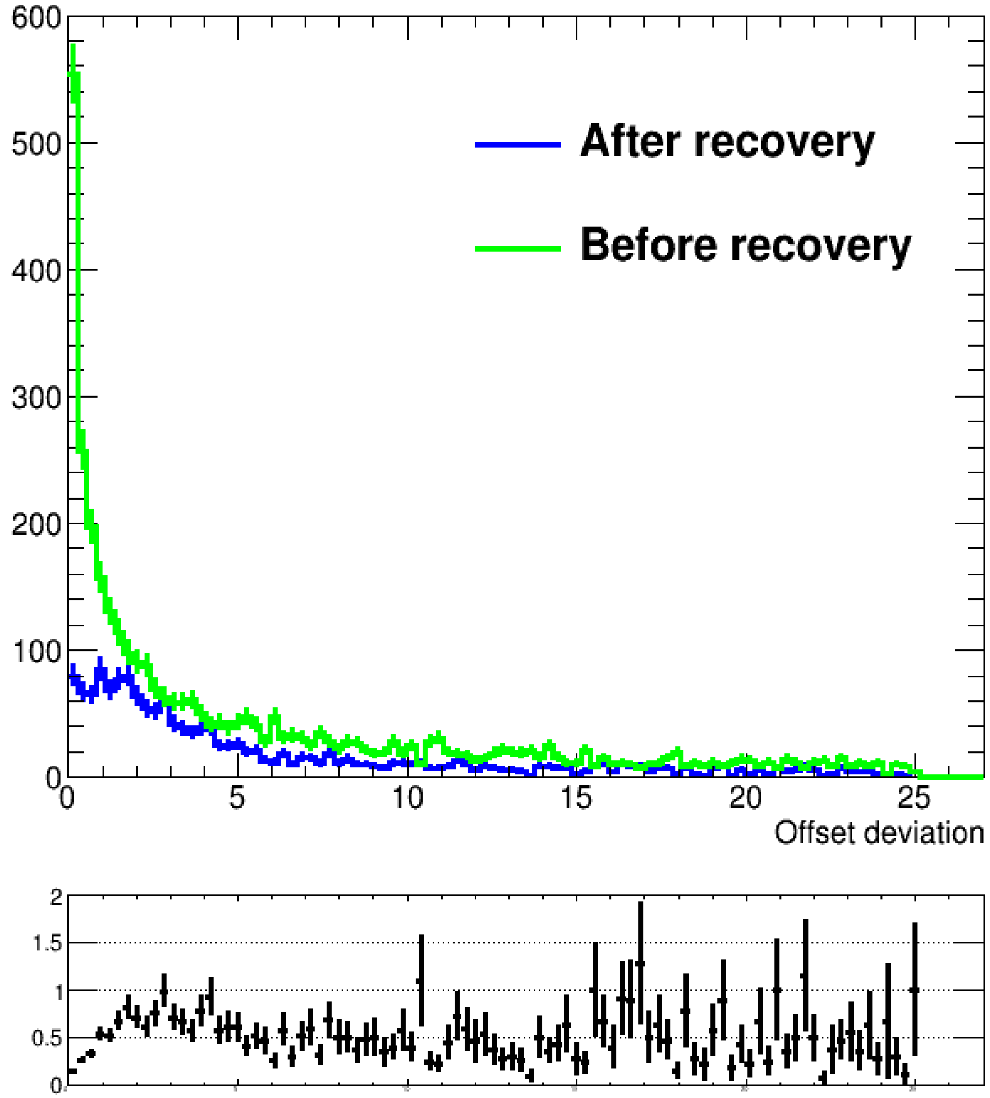


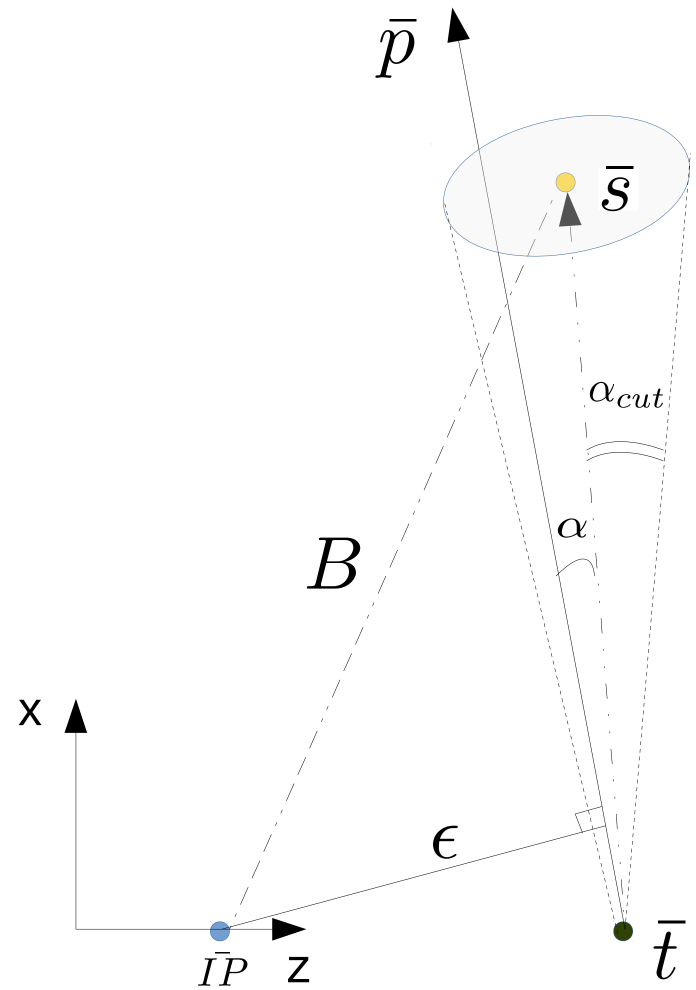
95.5% precision

- TruthVertexFinder works correctly!
- To reach this quality we should maximize the vertex reconstruction quality:
  - Recover corrupted vertices
  - Reject corrupted vertices
  - Apply different tracking algorithms
  - Use alternative vertexing algorithm

- The result of top asymmetry reconstruction with correctly reconstructed b vertices.

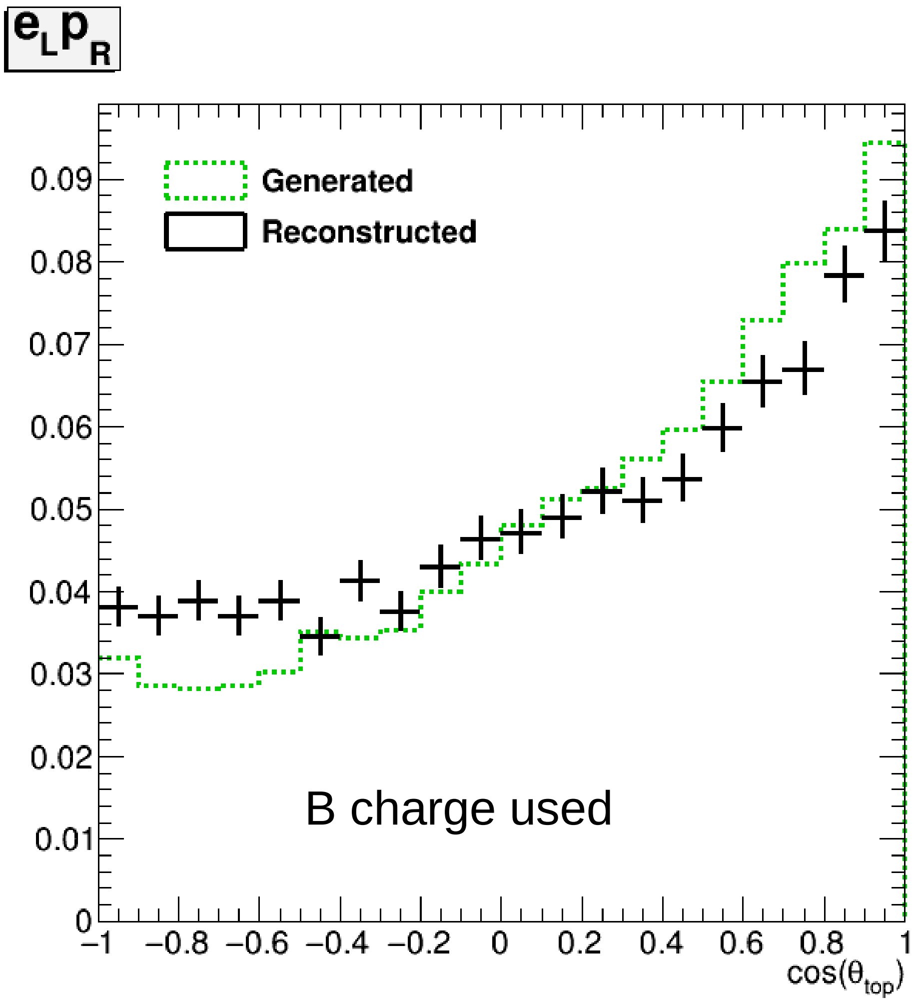
Offset deviation - Minivector reconstruction

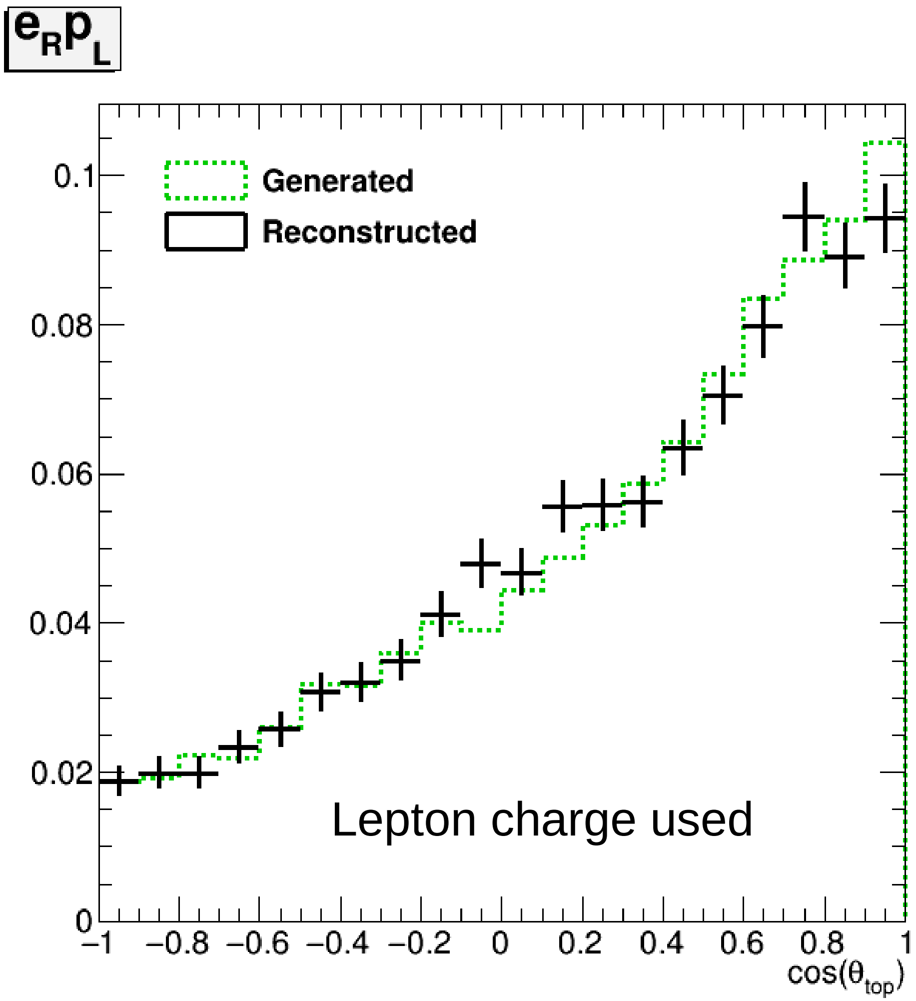




- Majority of missed tracks have low offsets. These tracks can be recoverable if their angle w.r.t. secondary vertex is small

Top asymmetry DBD



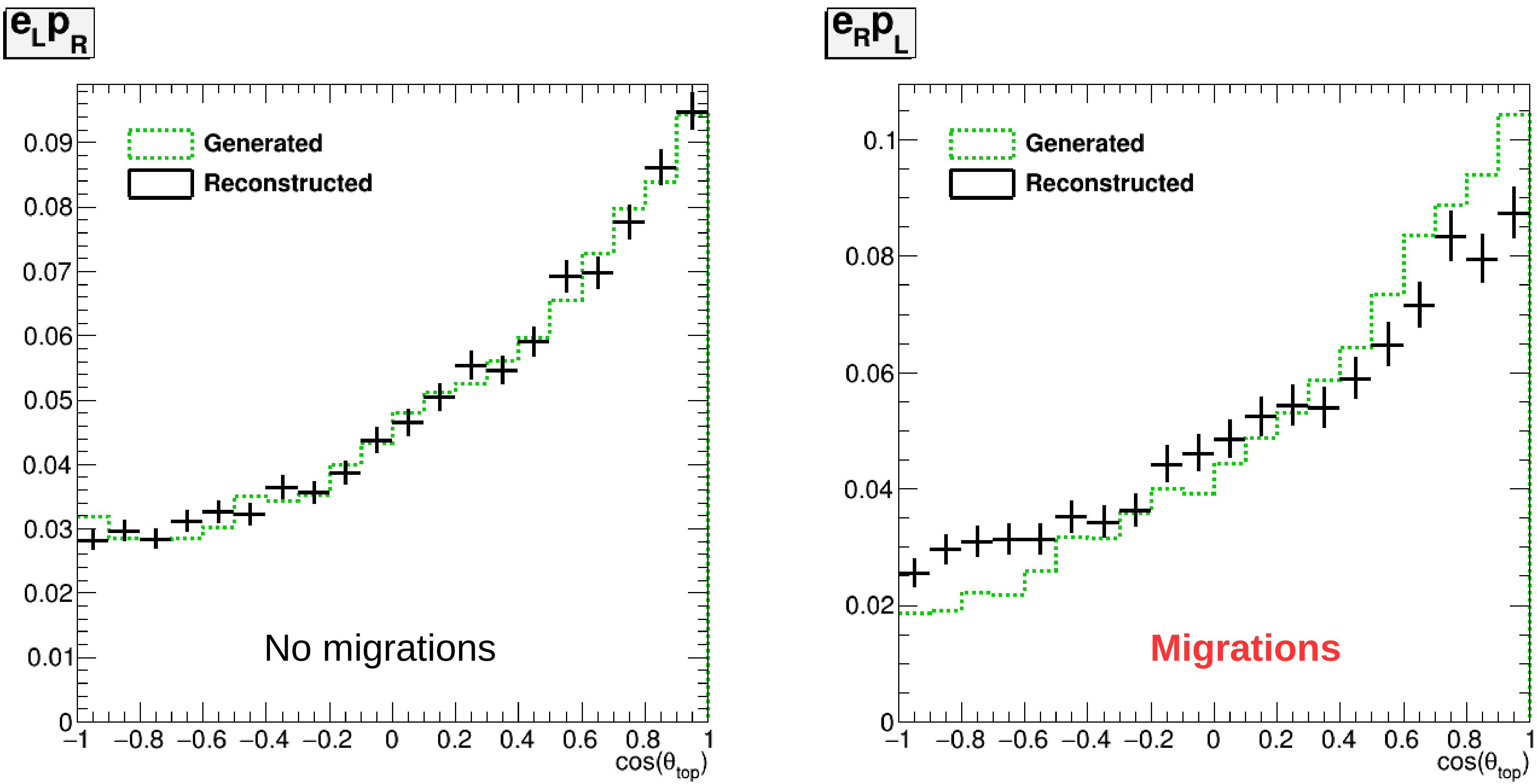


65.5% precision

96.3 % precision

- The result of top asymmetry reconstruction with real b charge measurement. DBD tracking, no recovery

Top asymmetry: Using generated b charge

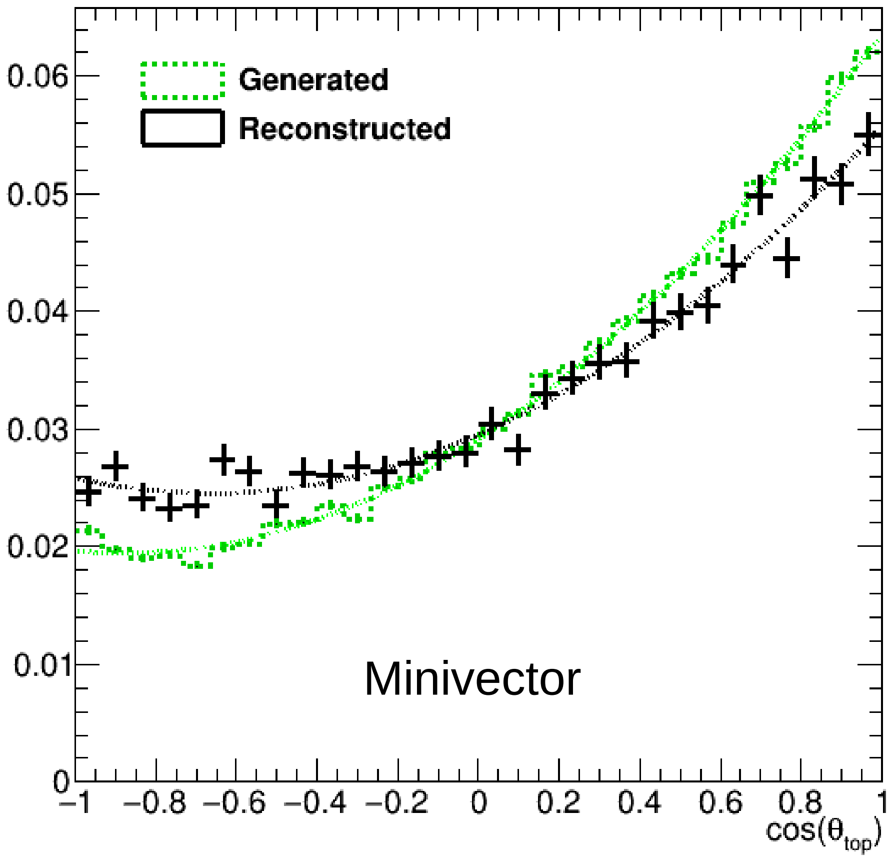


99.4% precision

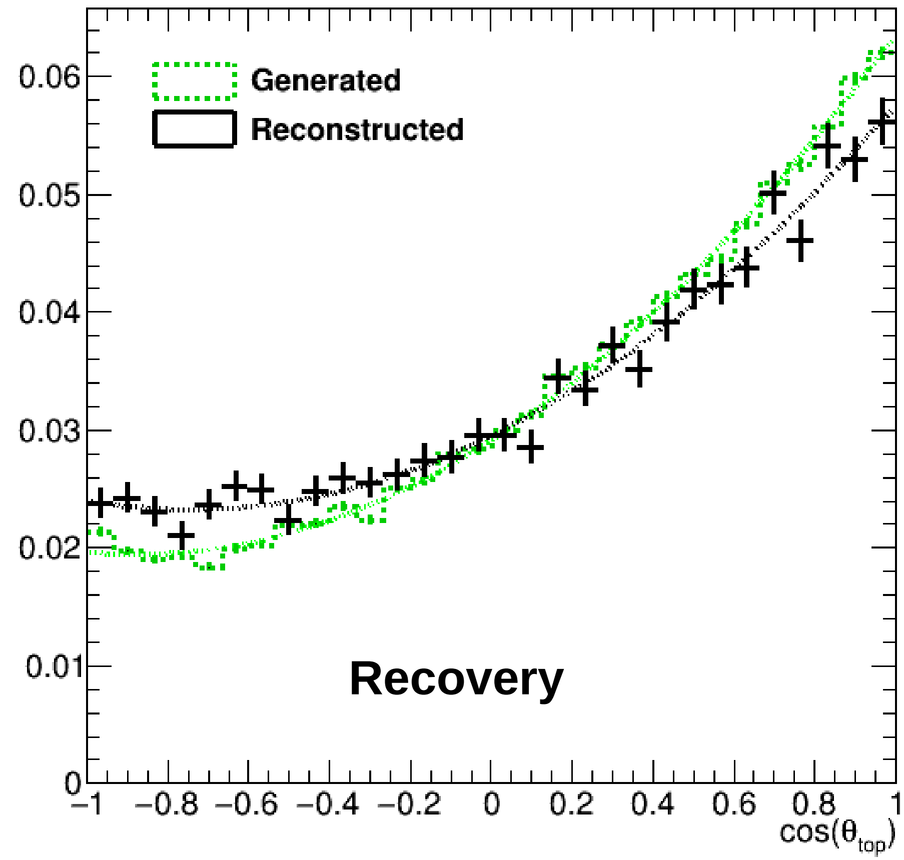
72.5% precision

- The result of top asymmetry reconstruction with 100% purity and efficiency of b charge.

Overall top polar angle improvement



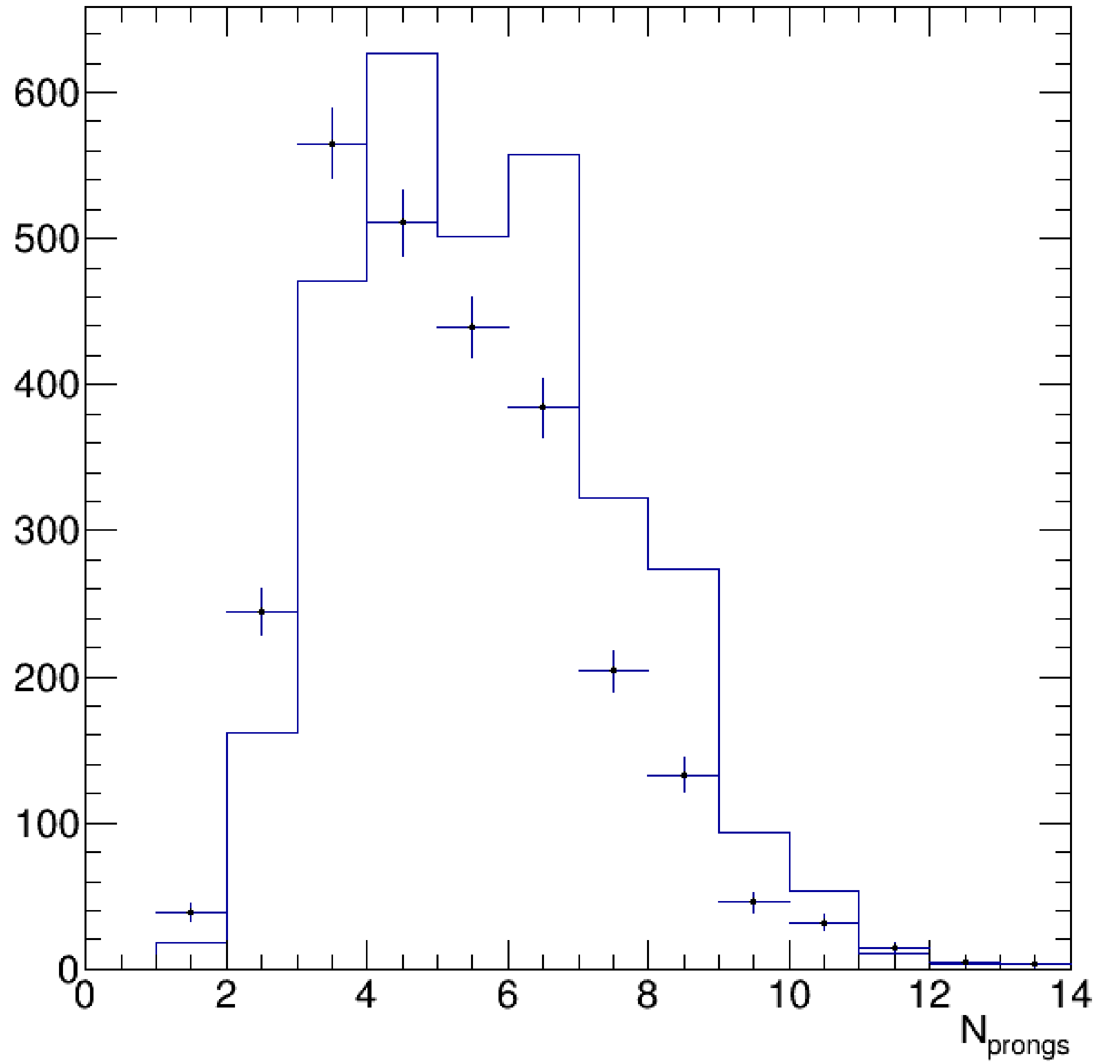
68% precision



75.% precision

- Top polar angle reconstruction for Minivector and Minivector + new recovery.
- LeptonFinder and flavour tagging is not optimized for minivector tracking

Reconstructed vertices



- Number of tracks from generated vertices (yellow) and reconstructed (crosses). Distributions do not coincide