LCFIPlus

The work is based on the collaboration but RY is responsible for this presentation.

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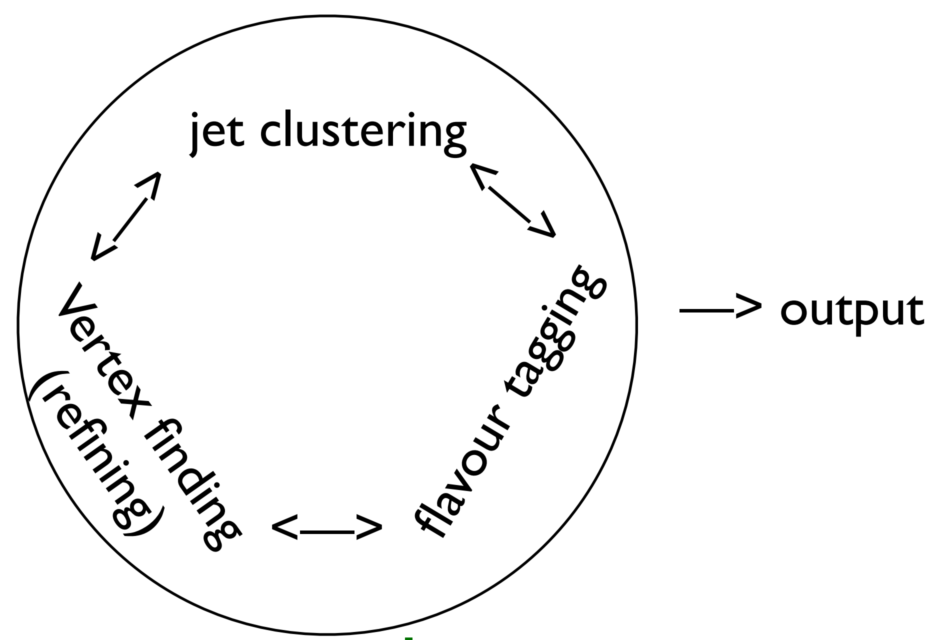
What's LCFIPlus?

❖ **A framework for jet flavour identification.**

- does vertex finding, jet clustering, and flavour tagging
- each process is implemented as a modular algorithm.
  - <u>gives flexibility to iterate or reverse the processes.</u>

w/o LCFIPlus : jet clustering —> vertex finding —> flavour tagging —> output

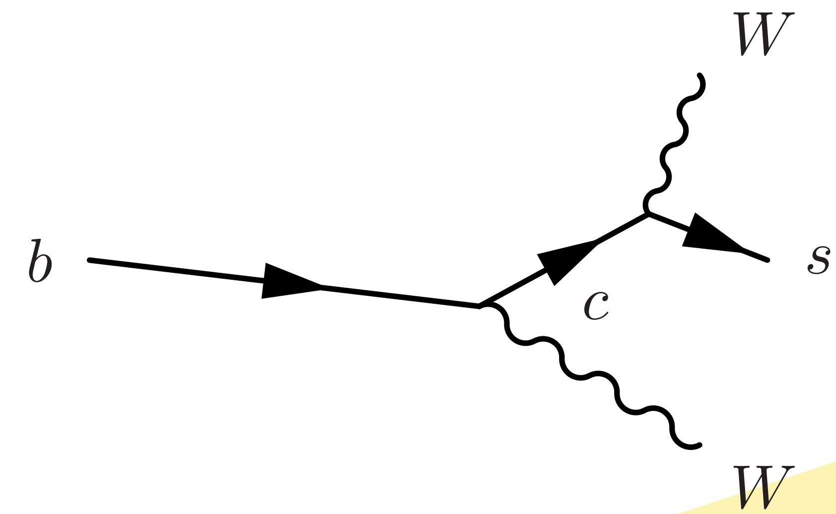
w/ LCFIPlus :



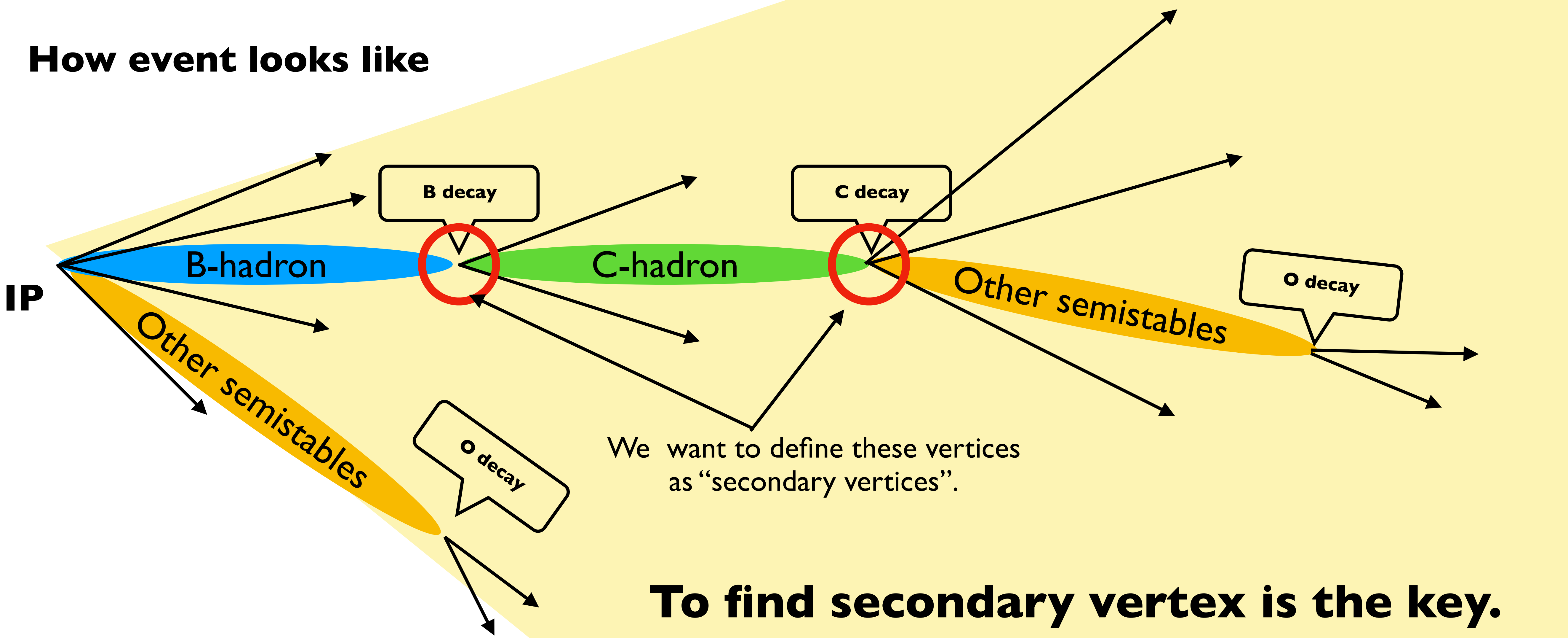
- It is flexible but typical usage is very simple;
  "vertex finding —> jet clustering —> vertex refining —>flavour tagging"
- originated from LCFIVertex (e.g. arXiv:0908.3019)
- you can find more details about LCFIPlus at e.g. arXiv:1506.08371

Principle of b-tag and c-tag

Feynman diagram



How event looks like



To find secondary vertex is the key.

Primary vertex finding

- **Track selection**
  - Define unreliable tracks and will not try to associate them to any vertices.
- **Beam spot constraint**
  - Beam spot constraint is useful to distinguish non-primary vertices.
- **TearDown algorithm**
  - Compute chi2, that is basically distance between a vertex point candidate and tracks, and find a best vertex candidate that gives a minimum chi2.
  - Remove a tracks that gives the highest contribution to the chi2.
  - Repeat until all the tracks satisfy a user-defined chi2 requirement.

Secondary vertex finding

- **Conventional way**
  - Use jet direction in order to reduce the possible number of track-combinations and thus reduce computational time.
  - It is possibly affected by jet mis-reconstruction.

- **Vertexing first in LCFIPlus**

- **Use tracks that are not associated to primary vertex.**
  - Make all possible track pairs, and requiring its invariant mass being less than 10GeV and sum of both track energies.
  - Apply V0 selection (vertex mass, vertex position etc.)
  - Attach additional tracks to the vertices if possible.

Jet clustering

- **Define jet cores (vertices or leptons) and combine nearest jet cores until the number of jets required is obtained.**
  - We do not want merge the jet cores any further. Set α = 100 when 2 jet cores are being combined.
- **Attach remaining tracks and neutral particles to one of the jet cores**

- **Jet alogrithms in LCFIPlus**
  - Durham
  - Kt
  - Valencia
  - DurhamVertex
  - KtVertex
  - ValenciaVertex

Modified y value (Durham case) :

$$Y(i,j) = \frac{2\min(E_i, E_j)^2 (1 - \cos\ \theta_{ij})}{Q^2} + \alpha$$

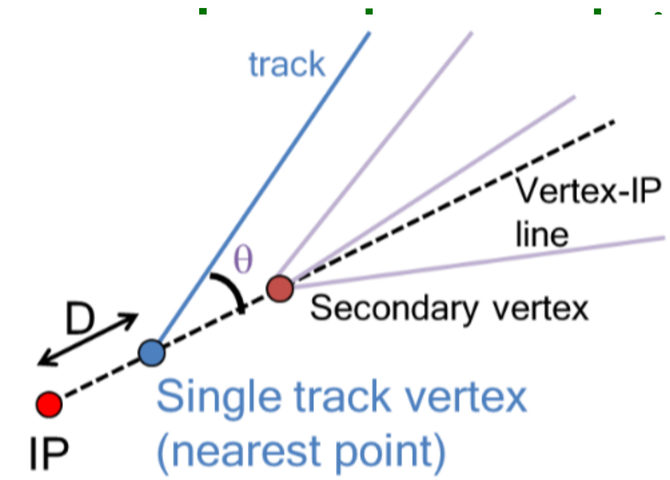
Ei,j : jet E
θij : angle b/w Jets
Q : √s
α=0, 100

- **Jet collections produced by external packages can also be used instead of using jet clustering in LCFIPlus.**

Vertex refining

- **Re-vertexing but now using jet information**
  - Secondary vertices more than 2 in a jet implies a b-jet.
  - Useful for b-c separation.
  - Try to improve the efficiency of secondary vertex reconstruction.

- **Pseudo vertex = 1 track vertex**
  - If one secondary vertex is found in a jet and if there is a track whose trajectory comes near a point collinear to the primary and secondary vertices, it is defined as pseudo ver s tagged as a primary track.



- **For each vertex in a jet, compute chi2 again to all tracks and check if there is any possibility to refine vertex reconstruction.**

Flavour tagging

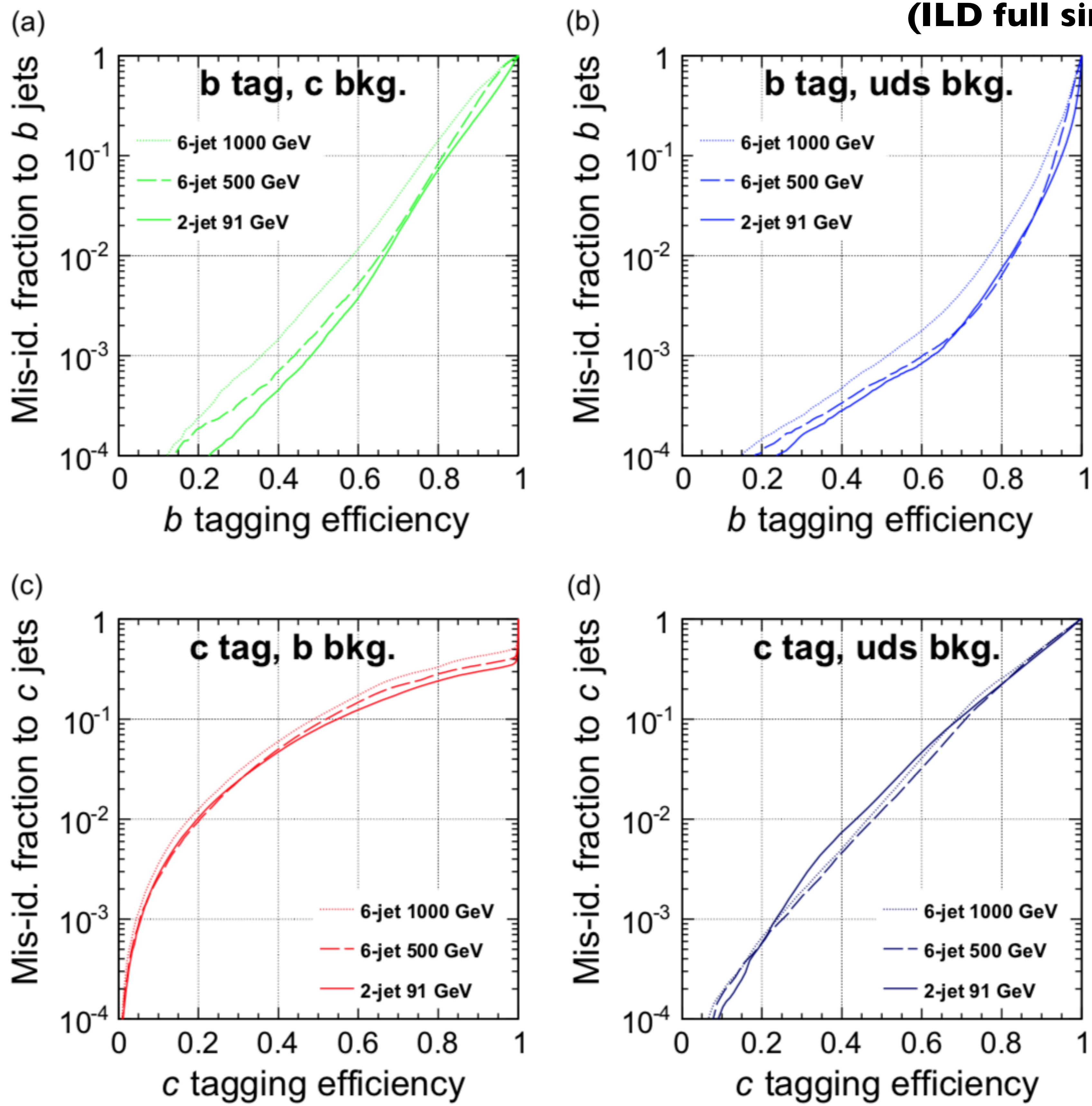
- **Based on multi-variate analysis ("BoostedDecisionTrees")**
  - input variables : impact parameters, track multiplicity, vertex mass, etc.

- **4 categories of jets for optimal jet flavour tagging**
  - 0 vertex jet —> light flavour like
  - 1 vertex jet —> c like
  - 2 vertex jet (pseudo vertex = 1) —> b like
  - 2+ vertex jet —> b like

- **Trainings depending on target processes aiming for better performance.**
  - 91GeV, 2b, 2c, 2q sample
  - 500GeV, 6b, 6c, 6q samples
  - 1TeV, 6b, 6c, 6q samples etc

Example of flavour tagging performance

(ILD full simulation (DBD))



There is still room for improvement

- **Feed additional information into multivariate analysis**
  - dEdx, TOF
- **Vertex mass recovery**
  - Pi0 reconstruction
- **Adaptive Vertex Fitting for vertex charge measurement**
  - currently relatively strict track selection is applied to prevent spoiling vertex reconstruction with fake tracks.
  - try to loosen the track selection while keeping fake track rate low by introducing a weight.
- **Identifying tracks from B-hadron (Bness)**
  - multivariate analysis
- **Probably more ...**

Vertex Mass Recovery

- Vertex mass is one of variables that distinguish B-hadron and C-hadron.

- Vertex mass can be computed only by charged tracks and thus is typically smaller than its original mass.

- If Pi0 is reconstructed as a part of vertex, adding the mass helps to recover the mass. —> Try to find a best assignment to a vertex using multivariate analysis (vertex mass, vertex track pids)

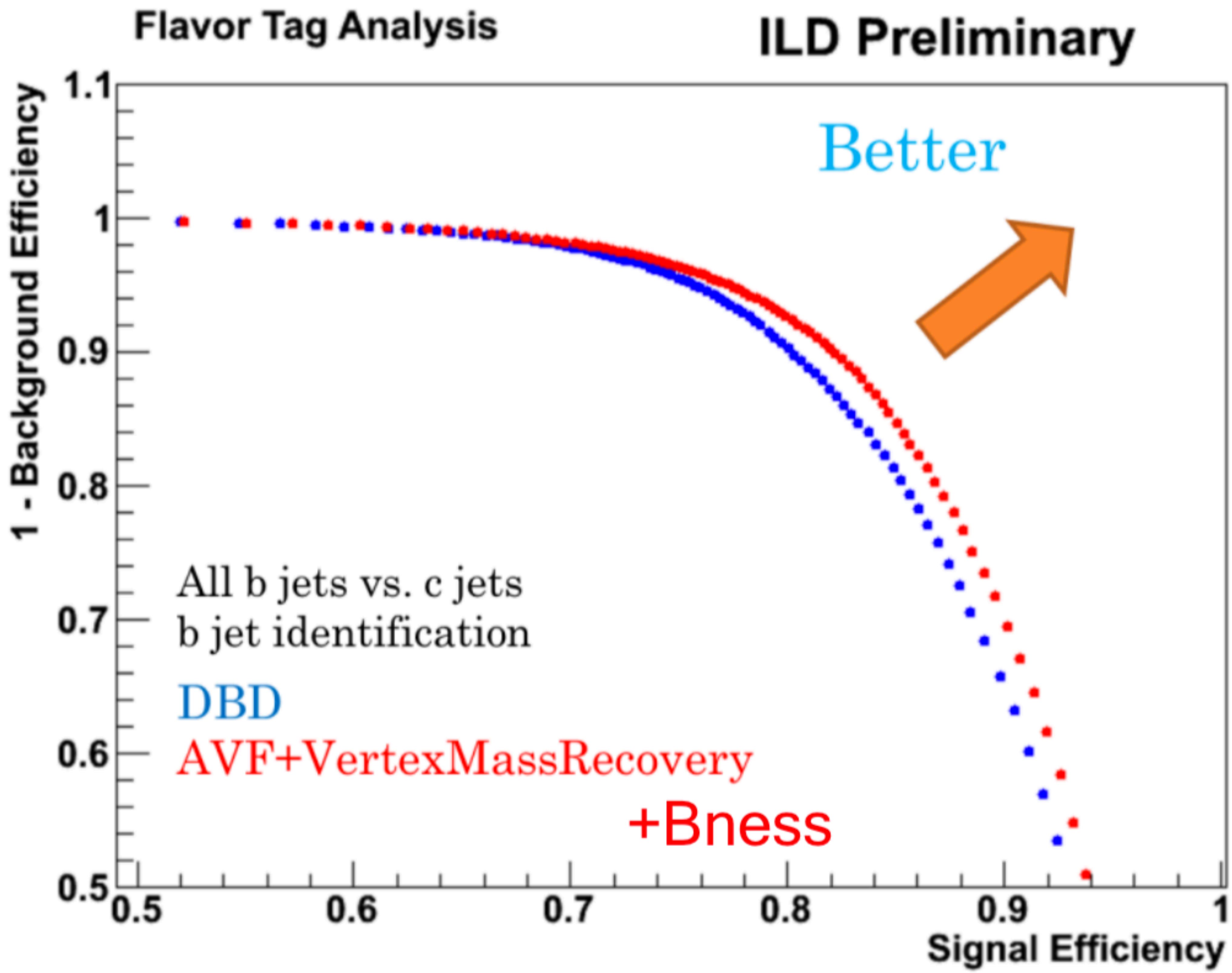
Adaptive Vertex Fitting in LCFIPlus

- **Outlier tracks**
  - mis-measured tracks
  - mis-assigned tracks to a vertex
  - Usually remove these tracks requiring chi2 to be small.

- **Compute following W for track 'n' and each vertex 'k'.**
  - T—> 0 case, W—> 1
  - T—> ∞ case, W —> 1 / (1+N)
  - χ_{cut} << χ_{nk} case, W —> always small
  - χ_{nk} << χ_{cut} case, W —> large only when no other good candidates.
  - —> Roughly speaking, the weight becomes large when the number of good track candidates is small.
  - When W > 0.5, the track 'n' will be associated to the vertex 'k'

$$w_{nk} = \frac{e^{-\chi^2_{nk}/2T}}{e^{-\chi^2_{\mathrm{cut}}/2T} + \sum_{i=1}^{N} e^{-\chi^2_{ik}/2T}}$$

Example of performance improvement



See more details e.g. Masakazu Kurata, LCWS@strasbourg, Oct. 2017

Summary

- **LCFIPlus is a framework for jet flavour tagging.**
  - Vertexing, Jet clustering, Flavour tagging
  - Still being updated to get better performance.

Backup

Table 6
Flavor tagging input variables. The category is defined in Table 4.

Name	Description	Normalization factor
trk1d0sig	$d0$ significance of track with highest $d0$ significance	1
trk2d0sig	$d0$ significance of track with second highest $d0$ significance	1
trk1z0sig	$z0$ significance of track with highest $d0$ significance	1
trk2z0sig	$z0$ significance of track with second highest $d0$ significance	1
trk1pt	Transverse momentum of track with highest $d0$ significance	$1/E_{\mathrm{jet}}$
trk2pt	Transverse momentum of track with second highest $d0$ significance	$1/E_{\mathrm{jet}}$
jprobr	Joint probability in the r–ϕ plane using all tracks	1
jprobr5sigma	Joint probability in the r–ϕ plane using all tracks having impact parameter significance exceeding 5 sigma	1
jprobz	Joint probability in the z projection using all tracks	1
jprobz5sigma	Joint probability in the z projection using all tracks having impact parameter significance exceeding 5 sigma	1
d0bprob	Product of b-quark probabilities of $d0$ values for all tracks, using b/c/q $d0$ distributions	1
d0cprob	Product of c-quark probabilities of $d0$ values for all tracks, using b/c/q $d0$ distributions	1
d0qprob	Product of q-quark probabilities of $d0$ values for all tracks, using b/c/q $d0$ distributions	1
z0bprob	Product of b-quark probabilities of $z0$ values for all tracks, using b/c/q $z0$ distributions	1
z0cprob	Product of c-quark probabilities of $z0$ values for all tracks, using b/c/q $z0$ distributions	1
z0qprob	Product of q-quark probabilities of $z0$ values for all tracks, using b/c/q $z0$ distributions	1
nmuon	Number of identified muons	1
nelectron	Number of identified electrons	1
trkmass	Mass of all tracks exceeding 5 sigma significance in $d0/z0$ values	1

Table 7
Flavor tagging input variables (continued).

Name	Description	Normalization factor
1vtxprob	Vertex probability with all tracks associated in vertices combined	1
vtxlen1	Decay length of the first vertex in the jet (zero if no vertex is found)	$1/E_{jet}$
vtxlen2	Decay length of the second vertex in the jet (zero if number of vertex is less than two)	$1/E_{jet}$
vtxlen12	Distance between the first and second vertex (zero if number of vertex is less than two)	$1/E_{jet}$
vtxsig1	Decay length significance of the first vertex in the jet (zero if no vertex is found)	$1/E_{jet}$
vtxsig2	Decay length significance of the second vertex in the jet (zero if number of vertex is less than two)	$1/E_{jet}$
vtxsig12	vtxlen12 divided by its error as computed from the sum of the covariance matrix of the first and second vertices, projected along the line connecting the two vertices	$1/E_{jet}$
vtxdirang1	The angle between the momentum (computed as a vector sum of track momenta) and the displacement of the first vertex	E_{jet}
vtxdirang2	The angle between the momentum (computed as a vector sum of track momenta) and the displacement of the second vertex	E_{jet}
vtxmult1	Number of tracks included in the first vertex (zero if no vertex is found)	1
vtxmult2	Number of tracks included in the second vertex (zero if number of vertex is less than two)	1
vtxmult	Number of tracks which are used to form secondary vertices (summed for all vertices)	1
vtxmom1	Magnitude of the vector sum of the momenta of all tracks combined into the first vertex	$1/E_{jet}$
vtxmom2	Magnitude of the vector sum of the momenta of all tracks combined into the second vertex	$1/E_{jet}$
vtxmass1	Mass of the first vertex computed from the sum of track four-momenta	1
vtxmass2	Mass of the second vertex computed from the sum of track four-momenta	1
vtxmass	Vertex mass as computed from the sum of four momenta of all tracks forming secondary vertices	1
vtxmasspc	Mass of the vertex with minimum pt correction allowed by the error matrices of the primary and secondary vertices	1
vtxprob	Vertex probability; for multiple vertices, the probability P is computed as $1-P=(1-P1)(1-P2)\cdots(1-PN)$	1