CLD detector performance with beam pipe with reduced diameter at IP - a first look -

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Introduction

✦ **CLD** (CLIC-Like Detector) is a detector concept developed for FCC-ee
✦ Design for the CDR (Dec 2018) adapted from the **CLICdet to the FCC-ee** interaction region specifics (crossing angle, magnets, beam pipe, background conditions)
✦ Performance satisfying the physics requirements

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**Novel design option post-CDR:**
✦ **beam pipe** at IP radius reduced from 15 mm to 10 mm
✦ CLD detector design adjusted to the new IR layout
Vertex detector - design update

- 3 double barrel layers + 3 double layer disks per side
- 0.6%$X_0$ per double layer
- Pixel size $25 \times 25 \, \mu m^2$
- Sensitive thickness $50 \, \mu m$ per layer

- **first double barrel layer closer to beam pipe**
- Third barrel layer unchanged
- Second barrel layer equidistant from first and third
- Vertex disks unchanged

<table>
<thead>
<tr>
<th></th>
<th>CDR</th>
<th>post-CDR</th>
</tr>
</thead>
<tbody>
<tr>
<td>beam pipe radius [mm]</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>r1 [mm]</td>
<td>17.5</td>
<td>12.5</td>
</tr>
<tr>
<td>r2 [mm]</td>
<td>18.5</td>
<td>13.5</td>
</tr>
<tr>
<td>r3 [mm]</td>
<td>37</td>
<td>35</td>
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<tr>
<td>r4 [mm]</td>
<td>38</td>
<td>36</td>
</tr>
<tr>
<td>r5 [mm]</td>
<td>57</td>
<td>57</td>
</tr>
<tr>
<td>r6 [mm]</td>
<td>58</td>
<td>58</td>
</tr>
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</table>
Transverse impact parameter resolution

- $\sigma(\Delta d_0)$ expected to improve with a vertex detector closer to the interaction point
- Results obtained in full detector simulation and reconstruction
- Resolution calculated as width of the Gaussian fit to the residual distribution per data point

**CDR**

\[
\sigma(\Delta d_0) = a + b/(p\sin(\theta))^3
\]

- $a = 5\mu m$
- $b = 15\mu m/GeV$

**post-CDR**

\[
\sigma(\Delta d_0) = a + b/(p\sin(\theta))^3
\]

- $a = 5\mu m$
- $b = 15\mu m/GeV$

- Improvement overall more visible for lower-energy muons
- Resolution for muons with momentum of 1 GeV also matches the design goal
Longitudinal impact parameter resolution

- $\sigma(\Delta z_0)$ expected to improve with a vertex detector closer to the interaction point
- Results obtained in full detector simulation and reconstruction
- Resolution calculated as width of the Gaussian fit to the residual distribution per data point

- Improvement overall more significant for lower-energy muons

![Graph showing longitudinal impact parameter resolution](image)
Flavour tagging algorithm

- Full simulation and reconstruction with LCFIPlus implemented in the Marlin framework of iLCSoft
- Algorithm chain:
  - vertex finder
  - jet clustering
  - vertex refiner
  - multivariate analysis

- dataset divided in 4 categories, used to train the BDT

<table>
<thead>
<tr>
<th>Category</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of vertices</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Number of pseudovertices*</td>
<td>0-2</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

*pseudovertices: b jets containing only one reconstructed secondary vertex with a possible track that could be interpreted as the result of an additional secondary decay. The cascade decays in a b jet are expected to result in decay points that are nearly collinear with the primary vertex. If only one secondary vertex is found, and if there is a track whose trajectory passes near a point collinear to the primary and secondary vertices, then the track is taken as a pseudo-vertex.
Flavour tagging for dijets at 365 GeV

- Flavour tagging relies on the capability of primary and secondary vertices reconstruction
  => expected to improve with a vertex detector closer to the interaction point
- Results obtained in full detector simulation and reconstruction
- Dijet events with $E_{cm} = 365$ GeV and $\theta = 80$ deg

Flavour tagging relies on the capability of primary and secondary vertices reconstruction expected to improve with a vertex detector closer to the interaction point. Results obtained in full detector simulation and reconstruction. Dijet events with $E_{cm} = 365$ GeV and $\theta = 80$ deg.
Flavour tagging relies on the capability of primary and secondary vertices reconstruction expected to improve with a vertex detector closer to the interaction point.

Results obtained in full detector simulation and reconstruction.

Dijet events with $E_{CM} = 365$ GeV and $\theta = 50$ deg

FCC-ee work in progress

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<table>
<thead>
<tr>
<th>Diagram 1</th>
<th>Diagram 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Misidentification eff.</td>
<td>Misidentification eff.</td>
</tr>
<tr>
<td>$E_{CM} = 365$ GeV, $\theta = 50^\circ$</td>
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</tr>
<tr>
<td>Charm contamination</td>
<td>Charm contamination</td>
</tr>
<tr>
<td>$o1_v04/o2_v01$</td>
<td>$o1_v04/o2_v01$</td>
</tr>
</tbody>
</table>

FCC-ee work in progress

- **dashed** = CDR
- **solid** = post-CDR

---

Flavour tagging:

- Flavour tagging relies on the capability of primary and secondary vertices reconstruction.
- Results obtained in full detector simulation and reconstruction.
- Dijet events with $E_{CM} = 365$ GeV and $\theta = 50$ deg.

Clarity of image: The text is clear and readable, with no issues related to lighting, blurriness, or text obfuscation.
Flavour tagging for dijets at 365 GeV

- Flavour tagging relies on the capability of primary and secondary vertices reconstruction => expected to improve with a vertex detector closer to the interaction point
- Results obtained in full detector simulation and reconstruction
- Dijet events with $E_{cm} = 365$ GeV and $\theta = 30$ deg

![Graphs showing Misidentification efficiency vs Beauty and Charm efficiency for FCC-ee work in progress.](image)

- FCC-ee work in progress
- Dijet events, $E_{cm} = 365$ GeV, $\theta = 30^\circ$
- Beauty contamination: FCCee_o1_v04, FCCee_o2_v01
- Charm contamination: FCCee_o1_v04, FCCee_o2_v01
- LF contamination: FCCee_o1_v04, FCCee_o2_v01

Legend:
- dashed = CDR
- solid = post-CDR

Clipped vertex reconstruction expected to improve with a vertex detector closer to the interaction point.

Results obtained in full detector simulation and reconstruction.
Flavour tagging for dijets at 365 GeV

- Flavour tagging relies on the capability of primary and secondary vertices reconstruction => expected to improve with a vertex detector closer to the interaction point
- Results obtained in full detector simulation and reconstruction
- Dijet events with $E_{cm} = 365$ GeV and $\theta = 20$ deg

\[ \text{Misidentification eff.} \]

\[ \text{Charm contamination} \]
\[ \text{LF contamination} \]

\[ \text{Beauty contamination} \]

\[ \text{FCCee\textunderscore o1\textunderscore v04} \]
\[ \text{FCCee\textunderscore o2\textunderscore v01} \]

\[ \text{FCC-ee work in progress} \]

\[ \theta = 20 \text{ deg} \]

\[ E_{cm} = 365 \text{ GeV} \]

\[ \text{dashed = CDR} \]
\[ \text{solid = post-CDR} \]

CLD detector performance with smaller beam pipe at IP | E. Leogrande (CERN)
Flavour tagging for dijets at 91 GeV

- Flavour tagging relies on the capability of primary and secondary vertices reconstruction
- Expected to improve with a vertex detector closer to the interaction point
- Results obtained in full detector simulation and reconstruction
- Dijet events with $E_{cm} = 91$ GeV and $\theta = 80$ deg

**Diagram:**
- Misidentification efficiency vs. Beauty efficiency for different contamination levels (Charm and LF) and two versions of FCC-ee detectors (o1_v04 and o2_v01).
- Comparison of Charm and Beauty contamination for FCC-ee detectors.

**Legend:**
- dashed = CDR
- solid = post-CDR

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CLD detector performance with smaller beam pipe at IP | E. Leogrande (CERN)
Flavour tagging for dijets at 91 GeV

- Flavour tagging relies on the capability of primary and secondary vertices reconstruction
  - Expected to improve with a vertex detector closer to the interaction point
- Results obtained in full detector simulation and reconstruction
- Dijet events with \( E_{cm} = 91 \text{ GeV} \) and \( \theta = 50 \text{ deg} \)

Results obtained in full detector simulation and reconstruction

Dijet events with \( E_{cm} = 91 \text{ GeV} \) and \( \theta = 50 \text{ deg} \)

FCC-ee work in progress

° \( = 50 \)
° \( \theta = 91 \text{ GeV} \), CM

Di-jet events, \( E_{cm} = 91 \text{ GeV} \) and \( \theta = 50 \text{ deg} \)

Misidentification eff.

Charm contamination

- FCCee_01_v04
- FCCee_02_v01

LF contamination

- FCCee_o1_v04
- FCCee_o2_v01

Charm eff.

FCCee work in progress

Dashed = CDR
Solid = post-CDR

Flavour tagging relies on the capability of primary and secondary vertices reconstruction.

Expected to improve with a vertex detector closer to the interaction point.

Results obtained in full detector simulation and reconstruction.

Dijet events with \( E_{cm} = 91 \text{ GeV} \) and \( \theta = 50 \text{ deg} \).

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Flavour tagging relies on the capability of primary and secondary vertices reconstruction expected to improve with a vertex detector closer to the interaction point.

Results obtained in full detector simulation and reconstruction.

Dijet events with $E_{cm} = 91$ GeV and $\theta = 30$ deg.

- Charm contamination
  - FCCee_o1_v04
  - FCCee_o2_v01
- Beauty contamination
  - FCCee_o1_v04
  - FCCee_o2_v01

FCC-ee work in progress.

Di-jet events, $E_{cm} = 91$ GeV, $\theta = 30^\circ$.

Dashed = CDR
Solid = post-CDR.
Flavour tagging for dijets at 91 GeV

- Flavour tagging relies on the capability of primary and secondary vertices reconstruction
  - expected to improve with a vertex detector closer to the interaction point
- Results obtained in full detector simulation and reconstruction
- Dijet events with $E_{cm} = 91$ GeV and $\theta = 20$ deg

Flavour tagging relies on the capability of primary and secondary vertices reconstruction expected to improve with a vertex detector closer to the interaction point.

Results obtained in full detector simulation and reconstruction.

Dijet events with $E_{cm} = 91$ GeV and $\theta = 20$ deg.

### Misidentification eff.

<table>
<thead>
<tr>
<th>$o_{1 _v04/o2 _v01}$</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charm contamination</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>FCCee_o1_v04</td>
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<td></td>
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<tr>
<td>FCCee_o2_v01</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>LF contamination</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FCCee_o1_v04</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>FCCee_o2_v01</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**FCC-ee work in progress**

$\theta = 20$ deg,

$E_{cm} = 91$ GeV,

Di-jet events, $E_{cm} = 91$ GeV, $\theta = 20$ deg.

**dashed = CDR**

**solid = post-CDR**

FL contamination

FCCee_o1_v04

FCCee_o2_v01

FCC-ee work in progress

$\theta = 20$ deg,

$E_{cm} = 91$ GeV,

Di-jet events, $E_{cm} = 91$ GeV, $\theta = 20$ deg.

**dashed = CDR**

**solid = post-CDR**

Beauty contamination

FCCee_o1_v04

FCCee_o2_v01

Di-jet events, $E_{cm} = 91$ GeV, $\theta = 20$ deg.

**dashed = CDR**

**solid = post-CDR**

Charm eff.

Dashed = CDR

Solid = post-CDR

CLD detector performance with smaller beam pipe at IP | E. Leogrande (CERN)
Preliminary observations

- **Flavour tagging** in dijet events at **365 GeV** improves *slightly* with post-CDR model
- **Flavour tagging** in dijet events at **91 GeV** improves *significantly* with post-CDR model
  - @365 GeV, the polar angle dependence shows that the improvement:
    - is better in the forward direction for the b-tagging
    - is similar in the forward and central direction for the c-tagging
  - @91 GeV, the polar angle dependence shows that the improvement:
    - is better in the forward direction for the b-tagging
    - is better in the central direction for the c-tagging
**Preliminary observations**

- **Flavour tagging** in dijet events at **365 GeV improves slightly** with post-CDR model
- **Flavour tagging** in dijet events at **91 GeV improves significantly** with post-CDR model
  - @365 GeV, the polar angle dependence shows that the improvement:
    - is better in the forward direction for the b-tagging
    - is similar in the forward and central direction for the c-tagging
  - @91 GeV, the polar angle dependence shows that the improvement:
    - is better in the forward direction for the b-tagging
    - is better in the central direction for the c-tagging

**Food for thoughts**

- **b tagging**
  - improvement stronger at 91GeV than at 365GeV <= fraction of b hadrons that decay after the innermost layer is smaller at 91GeV than at 365GeV
    - @91GeV & 90deg: ~10%, @365GeV & 90deg: ~50%
  - improvement stronger in the forward than in the central region at both energies <= fraction of b hadrons that decay after the innermost layer is smaller at 20deg than at 80deg
- tagging depends on many other variables: vertex mass, vertex resolution, impact parameter significance, … This is only the start of the investigation
Incoherent pairs background

- distribution of produced particles from incoherent pairs @91 GeV
  - old model
  - new model (smaller beampipe)

- occupancy in the barrel layers
  - old model x 50BX < 4x10^{-4}
  - new model x 50BX < 8x10^{-4}
  => still acceptable
Summary

✦ A new design for the CLD detector (post-CDR) has been realized for a new FCC-ee interaction region with a reduced beam pipe radius (15 mm —> 10 mm) at the IP
  ✦ vertex barrel closer to interaction point

✦ A very first look at the performance of the post-CDR CLD detector compared with the CDR model
  ✦ The impact parameter resolutions improve, especially for low momentum tracks
  ✦ The transverse momentum resolution is unaffected (not shown in the talk)
  ✦ The flavour tagging capabilities improve
  ✦ slightly for 365 GeV, strongly for 91 GeV
  ✦ with a dependence on polar angle observed

✦ Next step: analysis the flavour tagging results case by case
  ✦ vertexing performance, jet clustering and classification
  ✦ thorough investigation of the input variables to the BDT necessary
  ✦ + part of the problem is the long time for full simulation; place where fast sim tool would be extremely helpful

✦ Next² step: study effect of the background in the detector performance
  ✦ from preliminary study: incoherent pairs do not seem to represent an issue
Extra
$\cos(80^\circ) = 0.17$
$\eta = 0.18$

$\cos(70^\circ) = 0.34$
$\eta = 0.36$

$\cos(60^\circ) = 0.5$
$\eta = 0.55$

$\cos(50^\circ) = 0.64$
$\eta = 0.76$

$\cos(40^\circ) = 0.77$
$\eta = 1.01$

$\cos(30^\circ) = 0.87$
$\eta = 1.32$

$\cos(20^\circ) = 0.94$
$\eta = 1.73$

$\cos(10^\circ) = 0.98$
$\eta = 2.43$
LFCIPlus vertex finder algorithm

✦ **Vertex Fitter for Primary Vertex**
  - if beam spot is constrained, beam spot centre as initial 3D point
  - 3D fit performed for the vertex position by adding $\chi^2$ contribution from each track;
    tracks with highest $\chi^2$ and above a threshold are removed
  - *output*: minimized $\chi^2$, vertex uncertainty and probability, tracks associated to PV

✦ **Vertex Fitter for Secondary Vertices**
  - tracks not associated to the PV are paired and used as seeds for the SVs
  - 3D fit performed for the vertex position by adding $\chi^2$ contribution from each track pair;
    tracks with highest $\chi^2$ and above a threshold are removed + additional selection criteria
    (e.g. $V^0$ discarded)
  - additional tracks are added to the SV and accepted if $\chi^2$ contribution below threshold
  - at this point: tracks may have been used for more than one vertex
  - to remove overlap: vertices are scanned in order of probability (high to low) and
    number of tracks (3 to 2); tracks associated to vertices are removed from further SVs
  - *output*: minimized $\chi^2$, vertices uncertainty and probability, tracks associated to SVs
Tracks association

- Classification of tracks for vertex finder performance
  - Primary: tracks originated from the primary vertex
  - Bottom: tracks whose most immediate parent with a non-zero lifetime contains a b quark
  - Charm: tracks whose most immediate parent with a non-zero lifetime contains a c quark
  - Others: all other tracks (τ decays, strange hadrons, photon conversions, …)
<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Normalization factor</th>
<th>Used by category</th>
</tr>
</thead>
<tbody>
<tr>
<td>trk1d0sig</td>
<td>d0 significance of track with highest d0 significance</td>
<td>1</td>
<td>A, B, C, D</td>
</tr>
<tr>
<td>trk2d0sig</td>
<td>d0 significance of track with second highest d0 significance</td>
<td>1</td>
<td>A, B, C, D</td>
</tr>
<tr>
<td>trk1z0sig</td>
<td>z0 significance of track with highest d0 significance</td>
<td>1</td>
<td>A, B, C, D</td>
</tr>
<tr>
<td>trk2z0sig</td>
<td>z0 significance of track with second highest d0 significance</td>
<td>1</td>
<td>A, B, C, D</td>
</tr>
<tr>
<td>trk1pt</td>
<td>transverse momentum of track with highest d0 significance</td>
<td>$1/E_{\text{jet}}$</td>
<td>A, B, C, D</td>
</tr>
<tr>
<td>trk2pt</td>
<td>transverse momentum of track with second highest d0 significance</td>
<td>$1/E_{\text{jet}}$</td>
<td>A, B, C, D</td>
</tr>
<tr>
<td>jprobr</td>
<td>joint probability in the r-phi plane using all tracks</td>
<td>1</td>
<td>A, B, C, D</td>
</tr>
<tr>
<td>jprobr5sigma</td>
<td>joint probability in the r-phi plane using all tracks having impact parameter significance exceeding 5 sigma</td>
<td>1</td>
<td>A, B, C, D</td>
</tr>
<tr>
<td>jprobz</td>
<td>joint probability in the z projection using all tracks</td>
<td>1</td>
<td>A, B, C, D</td>
</tr>
<tr>
<td>jprobz5sigma</td>
<td>joint probability in the z projection using all tracks having impact parameter significance exceeding 5 sigma</td>
<td>1</td>
<td>A, B, C, D</td>
</tr>
<tr>
<td>d0bprob</td>
<td>product of b-quark probabilities of d0 values for all tracks, using b/c/q d0 distributions</td>
<td>1</td>
<td>A, B, C, D</td>
</tr>
<tr>
<td>d0cprob</td>
<td>product of c-quark probabilities of d0 values for all tracks, using b/c/q d0 distributions</td>
<td>1</td>
<td>A, B, C, D</td>
</tr>
<tr>
<td>d0qprob</td>
<td>product of q-quark probabilities of d0 values for all tracks, using b/c/q d0 distributions</td>
<td>1</td>
<td>A, B, C, D</td>
</tr>
<tr>
<td>z0bprob</td>
<td>product of b-quark probabilities of z0 values for all tracks, using b/c/q z0 distributions</td>
<td>1</td>
<td>A, B, C, D</td>
</tr>
<tr>
<td>z0cprob</td>
<td>product of c-quark probabilities of z0 values for all tracks, using b/c/q z0 distributions</td>
<td>1</td>
<td>A, B, C, D</td>
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<tr>
<td>z0qprob</td>
<td>product of q-quark probabilities of z0 values for all tracks, using b/c/q z0 distributions</td>
<td>1</td>
<td>A, B, C, D</td>
</tr>
<tr>
<td>nmuon</td>
<td>number of identified muons</td>
<td>1</td>
<td>A, B, C, D</td>
</tr>
<tr>
<td>nelectron</td>
<td>number of identified electrons</td>
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<td>A, B, C, D</td>
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<td>trkmass</td>
<td>mass of all tracks exceeding 5 sigma significance in d0/z0 values</td>
<td>1</td>
<td>A, B, C, D</td>
</tr>
<tr>
<td>Name</td>
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<td>------------</td>
<td>------------------------------------------------------------------------------</td>
<td>----------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>1vtxprob</td>
<td>vertex probability with all tracks associated in vertices combined</td>
<td>1</td>
<td>B, C, D</td>
</tr>
<tr>
<td>vtxlen1</td>
<td>decay length of the first vertex in the jet (zero if no vertex is found)</td>
<td>$1/E_{jet}$</td>
<td>B, C, D</td>
</tr>
<tr>
<td>vtxlen2</td>
<td>decay length of the second vertex in the jet (zero if number of vertex is less than two)</td>
<td>$1/E_{jet}$</td>
<td>D</td>
</tr>
<tr>
<td>vtxlen12</td>
<td>distance between the first and second vertex (zero if number of vertex is less than two)</td>
<td>$1/E_{jet}$</td>
<td>D</td>
</tr>
<tr>
<td>vtxsig1</td>
<td>decay length significance of the first vertex in the jet (zero if no vertex is found)</td>
<td>$1/E_{jet}$</td>
<td>B, C, D</td>
</tr>
<tr>
<td>vtxsig2</td>
<td>decay length significance of the second vertex in the jet (zero if number of vertex is less than two)</td>
<td>$1/E_{jet}$</td>
<td>D</td>
</tr>
<tr>
<td>vtxsig12</td>
<td>$vtxlen12$ 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</td>
<td>$1/E_{jet}$</td>
<td>D</td>
</tr>
<tr>
<td>vtxdirang1</td>
<td>the angle between the momentum (computed as a vector sum of track momenta) and the displacement of the first vertex</td>
<td>$E_{jet}$</td>
<td>B, C, D</td>
</tr>
<tr>
<td>vtxdirang2</td>
<td>the angle between the momentum (computed as a vector sum of track momenta) and the displacement of the second vertex</td>
<td>$E_{jet}$</td>
<td>D</td>
</tr>
<tr>
<td>vtxmult1</td>
<td>number of tracks included in the first vertex (zero if no vertex is found)</td>
<td>1</td>
<td>B, C, D</td>
</tr>
<tr>
<td>vtxmult2</td>
<td>number of tracks included in the second vertex (zero if number of vertex is less than two)</td>
<td>1</td>
<td>D</td>
</tr>
<tr>
<td>vtxmult</td>
<td>number of tracks which are used to form secondary vertices (summed for all vertices)</td>
<td>1</td>
<td>D</td>
</tr>
<tr>
<td>vtxmom1</td>
<td>magnitude of the vector sum of the momenta of all tracks combined into the first vertex</td>
<td>$1/E_{jet}$</td>
<td>B, C, D</td>
</tr>
<tr>
<td>vtxmom2</td>
<td>magnitude of the vector sum of the momenta of all tracks combined into the second vertex</td>
<td>$1/E_{jet}$</td>
<td>D</td>
</tr>
<tr>
<td>vtxmass1</td>
<td>mass of the first vertex computed from the sum of track four-momenta</td>
<td>1</td>
<td>B, C, D</td>
</tr>
<tr>
<td>vtxmass2</td>
<td>mass of the second vertex computed from the sum of track four-momenta</td>
<td>1</td>
<td>D</td>
</tr>
<tr>
<td>vtxmass</td>
<td>vertex mass as computed from the sum of four momenta of all tracks forming secondary vertices</td>
<td>1</td>
<td>B, C, D</td>
</tr>
<tr>
<td>vtxmasspc</td>
<td>mass of the vertex with minimum pt correction allowed by the error matrices of the primary and secondary vertices</td>
<td>1</td>
<td>B, C, D</td>
</tr>
<tr>
<td>vtxprob</td>
<td>vertex probability; for multiple vertices, the probability P is computed as $1-P = (1-P1)(1-P2)...(1-PN)$</td>
<td>1</td>
<td>B, C, D</td>
</tr>
</tbody>
</table>