Physics performance studies for different CLIC vertex detector geometries

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Overview

1. Reminder on the CLIC_SiD_CDR vertex detector geometry
2. Implementation of new vertex detector geometries for CLIC
   - spirals
   - double_spirals
3. Flavour tagging studies for the implemented geometries
   - double_spirals and spirals
   - spirals and CDR
   - double_spirals and CDR
4. Flavour tagging with increased material budget
5. Illustration of the impact of the flavour-tagging performance on the Higgs boson analysis
6. Conclusions

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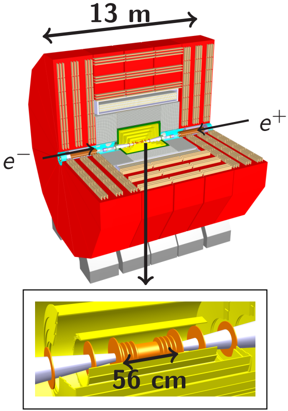
CLIC_SiD_CDR

- CLIC_SiD_CDR vertex detector :
  - 5 layers in barrel.
  - 4 disks in endcaps.
- A more realistic model for the vertex detector is under development in which:
  - Airflow cooling is used for the heat removal.
  - Double-layered sensors are considered to reduce the mechanical support material.

▸ Vertex-detector R&D for CLIC, Mathieu Benoit



- Goal :
  - Compare the performance of different vertex detector models for jet flavour identification (flavour tagging).
  - Study the effect of the material budget on the flavour-tagging performance.

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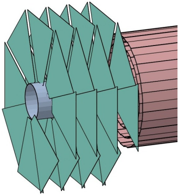
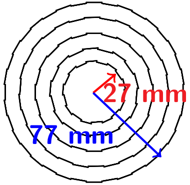
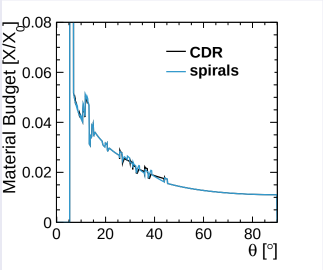
The spirals geometry

- Spiral arrangement of the sensors in the vertex endcaps (instead of disks) to allow for airflow cooling.
- Has the same barrel as the CDR geometry.
- Material budget: 0.11% X_0 per layer.
- The simulated material budget for the vertex detector (including the beam pipe) averaged over ϕ:



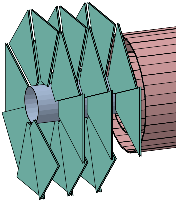


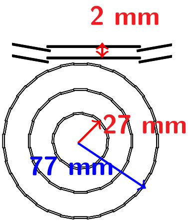
X/X_0



The double_spirals geometry

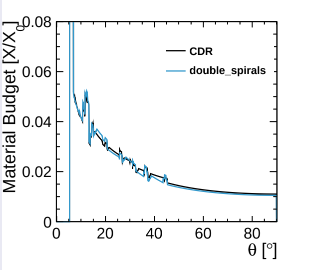
- Consists of double-layered sensors.
- Material budget: 0.18% X_0 per double layer.
- Contains 3 layers in the barrel and 3 layers in the endcaps.





- The simulated material budget for the vertex detector (including the beam pipe) averaged over ϕ:

X/X_0



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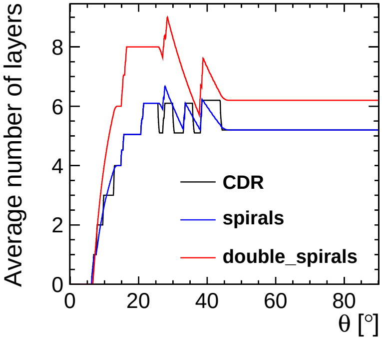
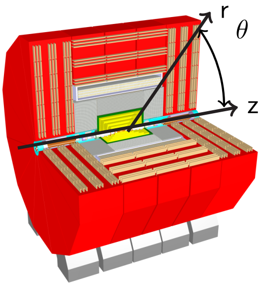
The Coverage of the Vertex Detector

- Average number of sensitive layers (averaged over the azimuthal angle ϕ):





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Simulations strategy

- The impact of the new geometries is evaluated using the flavour-tagging performance based on the full simulation of the detector (cannot be done analytically).
- Dijet events (without ISR and Beamstrahlung) at center-of-mass energies of $\sqrt{s}$ =91 GeV, 200 GeV and 500 GeV with polar angles $\theta = 10^\circ, 20^\circ, ..., 90^\circ$ are considered.
- 80000 events are considered for each process:
  $e^+e^- \rightarrow b\bar{b}$
  $e^+e^- \rightarrow c\bar{c}$
  $e^+e^- \rightarrow u\bar{u}, d\bar{d}, s\bar{s} \Rightarrow$ light-flavoured (LF) jets
- 50% of the events are used for training the Boosted Decision Trees (BDTs) classifier and 50% for testing. The mass and the decay length significance of the vertices are the most important input variables.

Software versions used:

- SLIC v3r0p3
- org.lcsim 2.5
- LCFIPlus v0.52

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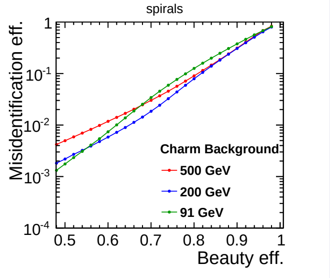
Flavour tagging and jet energy dependence

- Flavour-tagging performance is dependent on the jet energy.
- Example:
  - x-axis: the efficiency of b tagging.
  - y-axis: the probability to misidentify **charm jets** as **b jets**.
    ⇒The lower, the better!
  - Geometry: **spirals**
  - Dijet events: with a **mixture** of different polar angles.

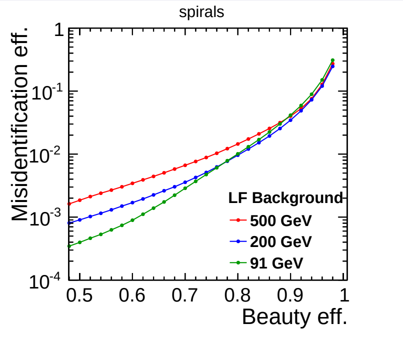
b-tag: charm background



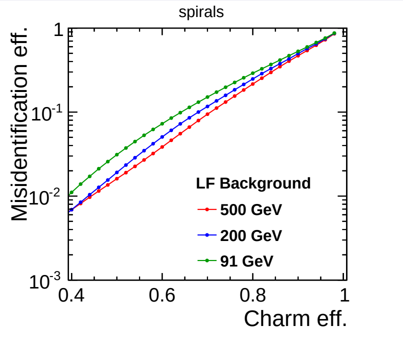
Flavour tagging and jet energy dependence (2)

- Geometry: **spirals**.
- Dijets events with a mixture of polar angles.

b-tag: LF background



c-tag: LF background

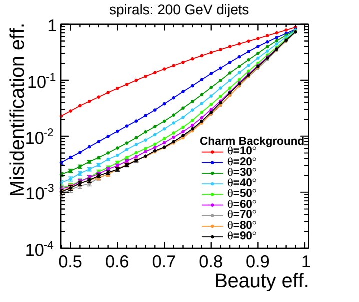


- In general, b tagging:
  - gets better for jets at lower energies.
  - has a better performance than c tagging.

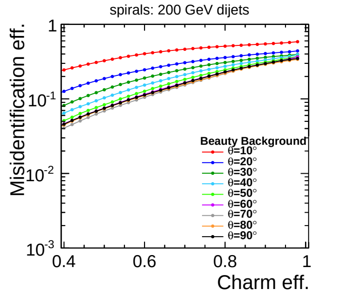
Flavour tagging and jet angle dependence

- Geometry: **spirals**.
- Dijets at: **200 GeV**.

b-tag: charm background



c-tag: beauty background



- For low polar angles, the performance decreases due to several factors:
  - Losses in the beam pipe.
  - Low number of detecting layers.
  - Low impact parameter resolutions.

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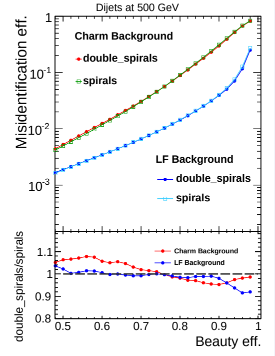
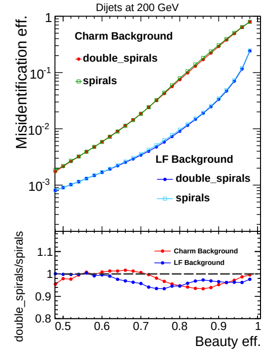
double_spirals vs. spirals: b-tag performance

- Global comparison between the single and double layer approaches: a mixture of jets with different polar angles is considered.

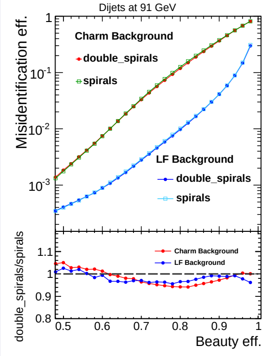
Dijets at 500 GeV



Dijets at 200 GeV



Dijets at 91 GeV

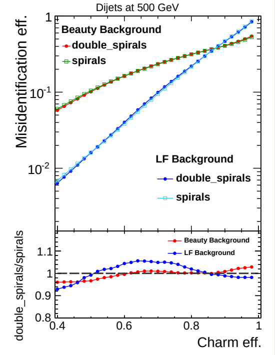


- Both geometries have very similar b-tag performance.

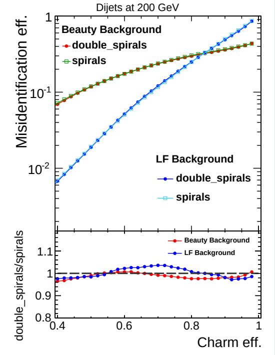
double_spirals vs. spirals: c-tag performance

- Global comparison between the single and double layer approaches: a mixture of jets with different polar angles is considered.

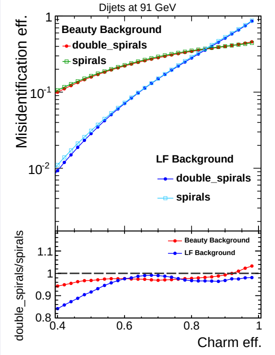
Dijets at 500 GeV



Dijets at 200 GeV



Dijets at 91 GeV



- The double_spirals geometry improves the misidentification efficiency of light-flavoured jets at 91 GeV.

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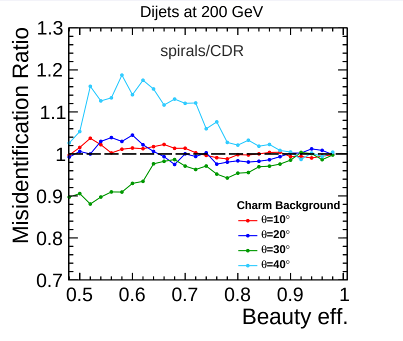
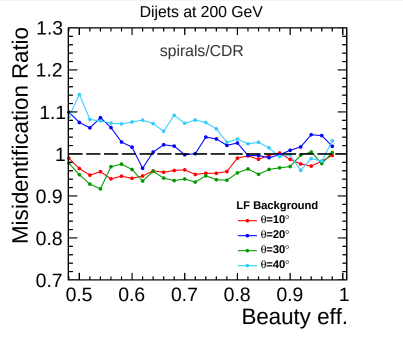
spirals vs. CDR: b-tag performance

- Dijets at: **200 GeV**

b-tag: charm background



b-tag: LF background



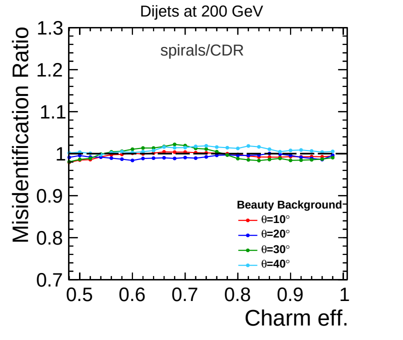
- Both geometries have similar b-tag performance except for jets at $\theta = 40^\circ$

slide 25

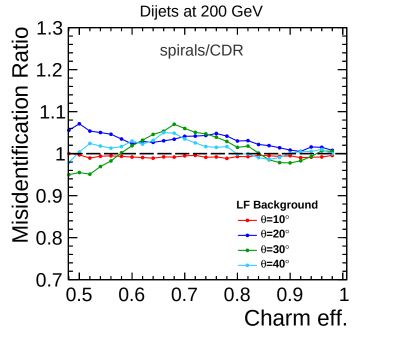
spirals vs. CDR: c-tag performance

- Dijets at: **200 GeV**

c-tag: beauty background



c-tag: LF background



- Both geometries have very similar c-tag performance.

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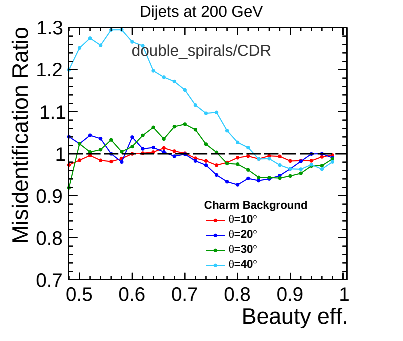
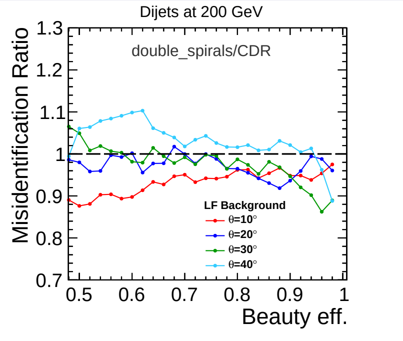
double_spirals vs. CDR: b-tag performance

- Dijets at: **200 GeV**

b-tag: charm background



b-tag: LF background



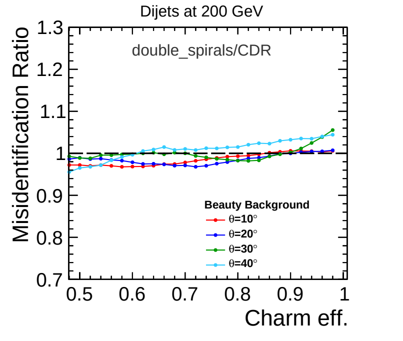
- Both geometries have similar b-tag performance except for jets at $\theta = 40^\circ$

slide 25

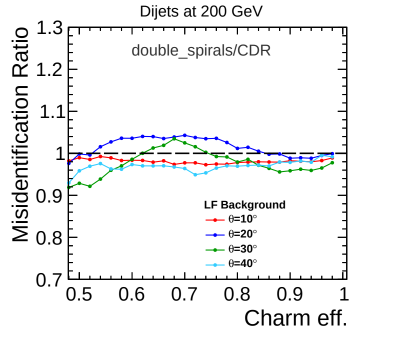
double_spirals vs. CDR: c-tag performance

- Dijets at: **200 GeV**

c-tag: beauty background



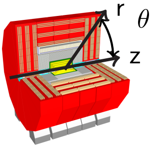
c-tag: LF background

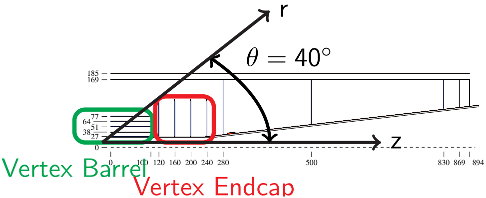


- Both geometries have very similar c-tag performance.

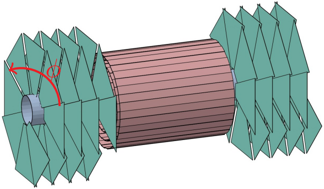
Flavour tagging at $\theta = 40^\circ$

- The b tagging at $\theta = 40^\circ$ has higher background for the spiral geometries (up to 30% for the double_spirals geometry).
- At this angle, there is the transition between the vertex endcaps and the barrel. Less sensitive layers are hit in the spiral for certain ϕ angles.





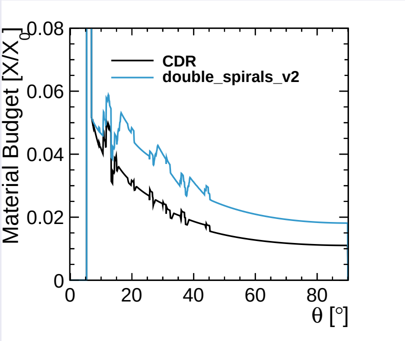
- This effect can be potentially improved by using a ϕ dependent optimization of the track reconstruction.



The double_spirals_v2 geometry

- A more realistic double_spirals geometry with 0.4% X_0 per double layer considering:
  - the mechanical support.
  - powering for the pixel detectors.
- The simulated material budget for the vertex detector (including the beam pipe) averaged over ϕ:

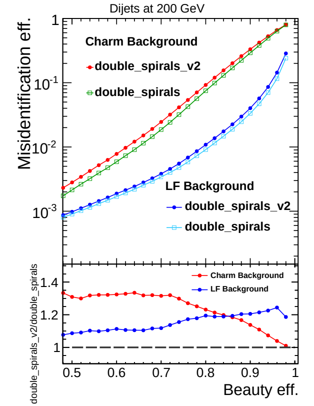
X/X_0



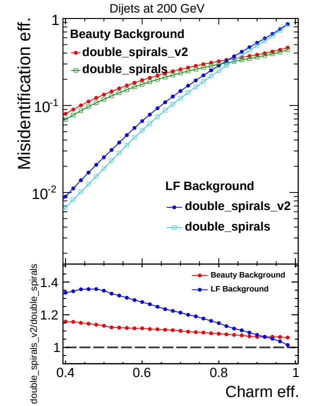
double_spirals_v2 vs. double_spirals

- Dijets at **200 GeV** with a mixture of polar angles are considered.

b-tag: dijets at 200 GeV



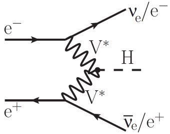
c-tag: dijets at 200 GeV



- By increasing the material budget, the fake rate increases by up to 40%.

Flavour-tagging performance and the Higgs boson analysis

- At 3 TeV the production of the 125 GeV Higgs boson is dominated by the process: $e^+e^- \rightarrow H\nu\bar{\nu}$
  ▸ LCD-Note-2011-036



- The effect of ±20% change of fake rates on the $\sigma \times$BR measurement:

Precisions on:	$\sigma(e^+e^- \rightarrow H\nu\bar{\nu})\times BR(H\rightarrow b\bar{b})$	$\sigma(e^+e^- \rightarrow H\nu\bar{\nu})\times BR(H\rightarrow c\bar{c})$
Default	0.23%	3.1%
+20% fake rates	0.24%	3.6%
-20% fake rates	0.21%	2.6%

- A 20% change in the fake rate for LF jets leads to 6-7% effect on the precision of $H\rightarrow b\bar{b}$.
- A 20% change in the fake rate for LF jets and b jets leads to 15% effect on the precision of $H\rightarrow c\bar{c}$.

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Conclusions

- Two new concepts for the CLIC vertex detector have been implemented: spirals and double_spirals geometries.
- The impact of the new geometries on the flavour tagging is too complex to be estimated analytically as it depends on many factors ⇒ full simulation is needed.
- In general, the performance of the different geometries is rather similar:
  - The spirals and double_spirals geometries have very similar performances.
  - For jets at 40°, the CDR geometry shows better b-tag performance than the spirals geometries ⇒ the track reconstruction should be optimized.
- By increasing the material budget (in the double_spirals_v2 geometry), the flavour-tagging performance decreases by up to 40% compared to the double_spirals geometry.
  - Investigation for other jet energies is ongoing.

Thank you for your attention!

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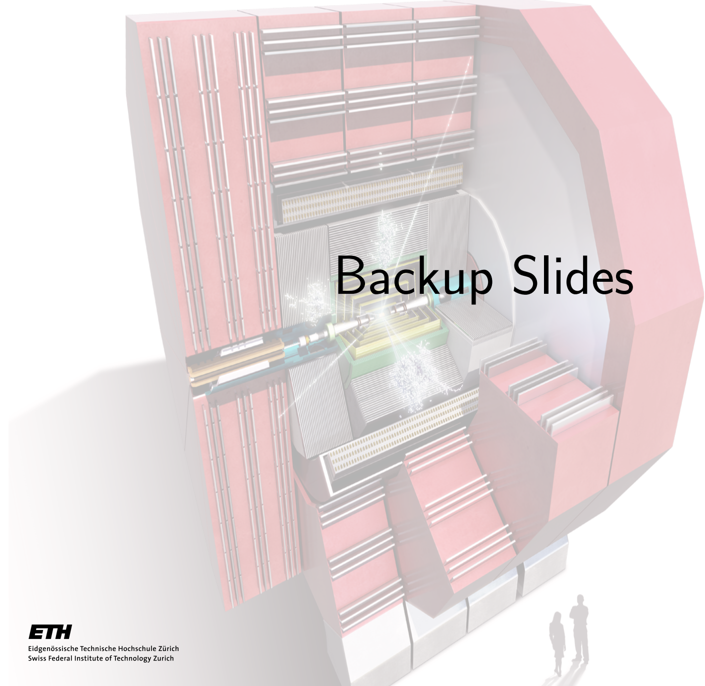

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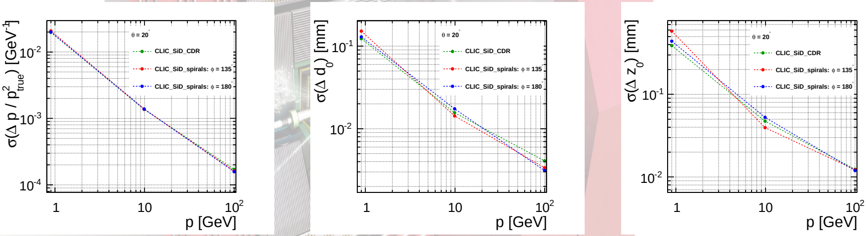
Impact parameter resolutions: spirals geometry



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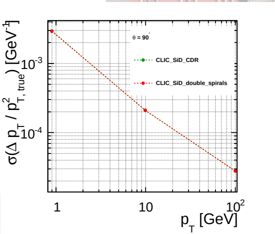
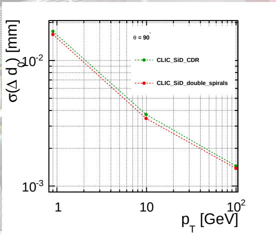
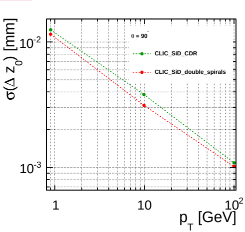
Impact parameter resolutions: double_spirals geometry

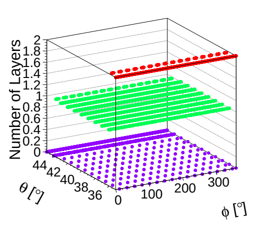




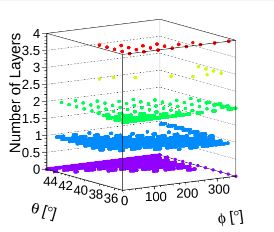


Number of Layers at $\theta = 40^\circ$

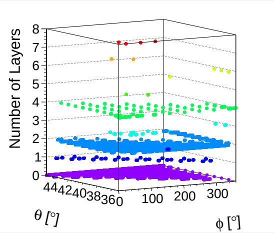
CDR



spirals



double_spirals



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