Updates on Conformal Tracking (and flavour tagging)

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Conformal Tracking Paper

- **General description of the conformal tracking**
  - Conformal mapping
  - Cellular Automaton-based track finding
- **Track reconstruction at CLIC**
  - Experimental conditions and challenges
  - Application of conformal tracking in CLICdet
  - Performance

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Conformal Tracking for all-silicon trackers at future electron–positron colliders

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Abstract

Conformal tracking is an innovative and comprehensive pattern recognition technique using a cellular automaton-based track finding performed in a conformally-mapped space. It is particularly well-suited for light-weight silicon systems with high position resolution, such as the next generation of tracking detectors designed for future electron–positron colliders. The algorithm has been developed and validated with simulated data of the CLICdet tracker. It has demonstrated not only excellent performance in terms of tracking efficiency, fake rate and track parameters resolution but also robustness against the high beam-induced background levels. Thanks to its geometry-agnostic nature and its modularity, the algorithm is very flexible and can easily be adapted to other detector designs and experimental environments at future e⁺e⁻ colliders.

This work was carried out in the framework of the CLICdp Collaboration

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CLICdp

Single μ^-
- prompt, p = 100 GeV
- prompt, p = 400 MeV
- non-prompt, p = 100 GeV

CLICdp

$b\bar{b}$, E_{CM} = 500 GeV, no background
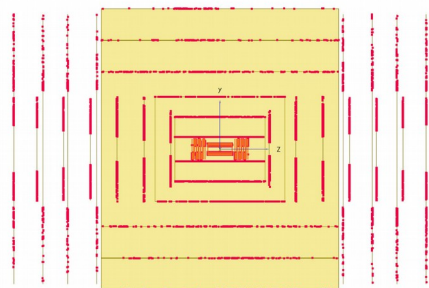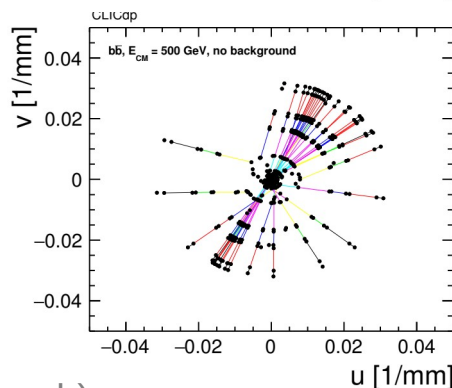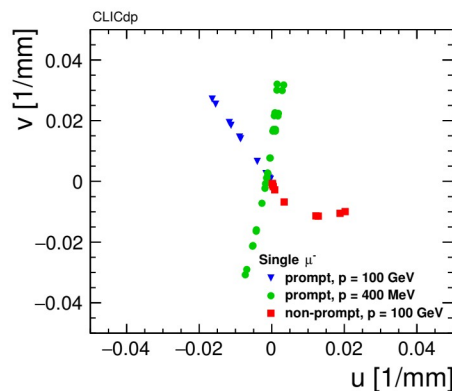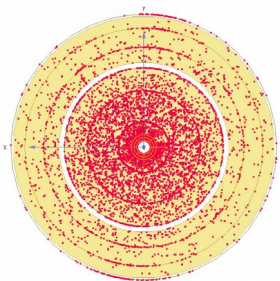
Some highlights

- **Performance for isolated particles**
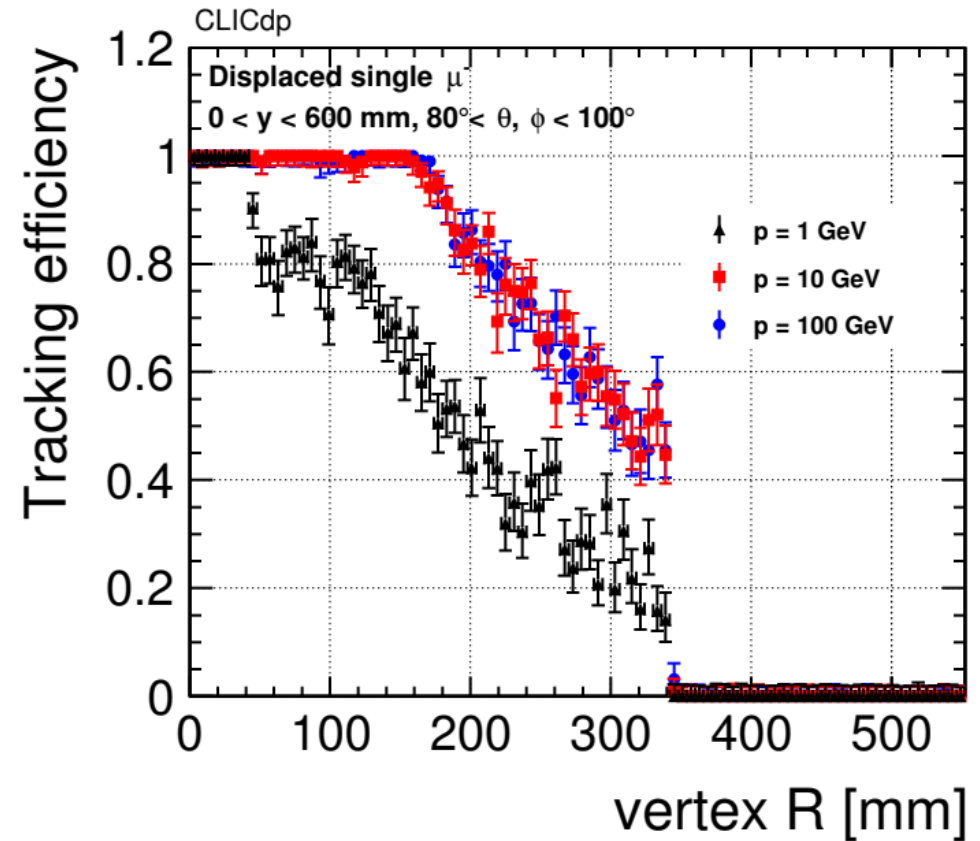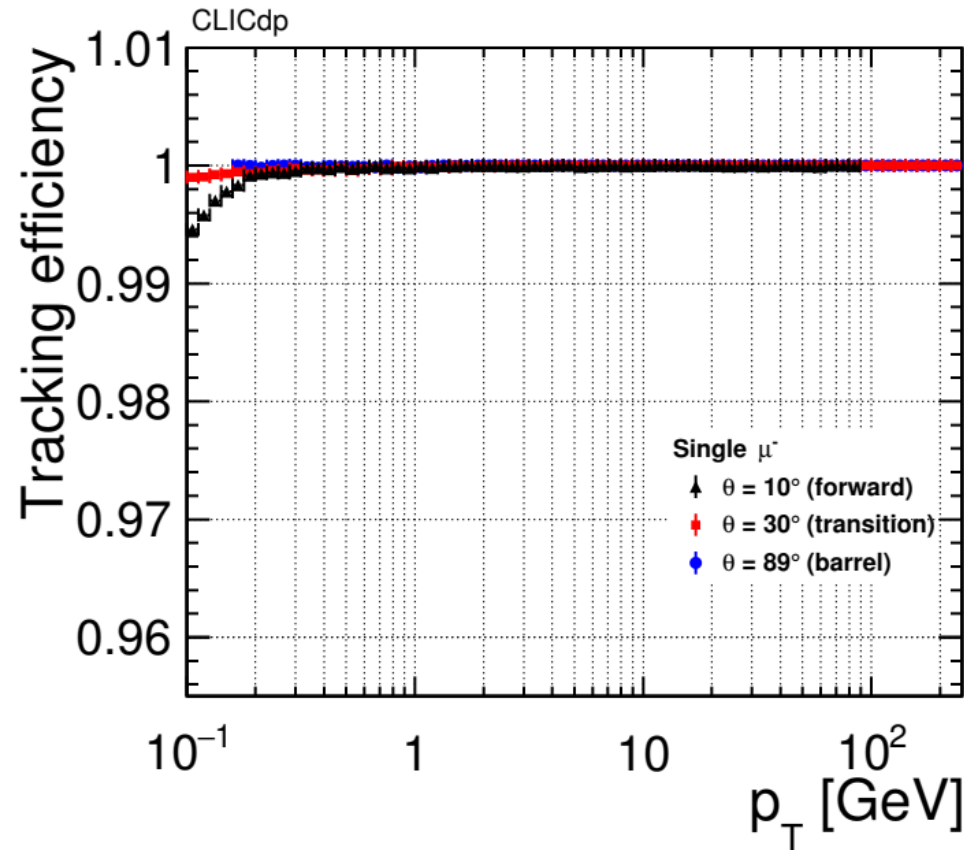
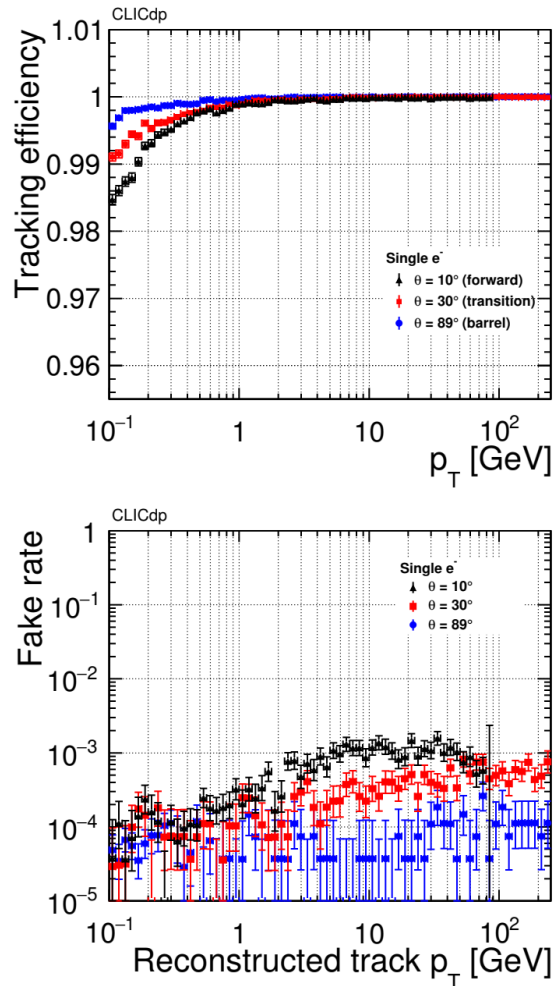- Tracking fully efficient in the entire tracker volume and with transverse momentum > 0.1 GeV

- Tracking fully efficient also for displaced tracks → full coverage for b-decay

- Meet target values of required performance on track parameters resolution

Some highlights
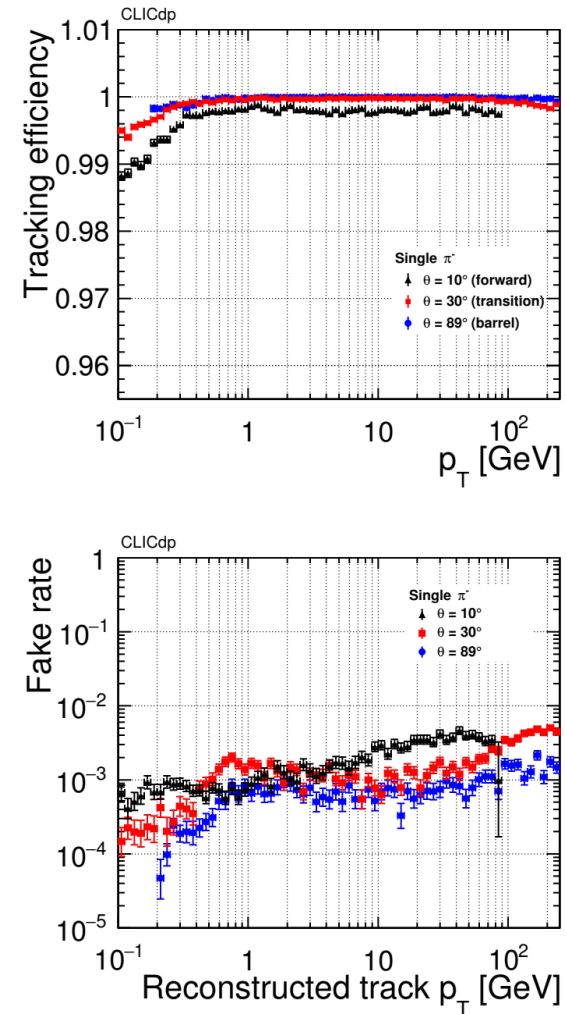
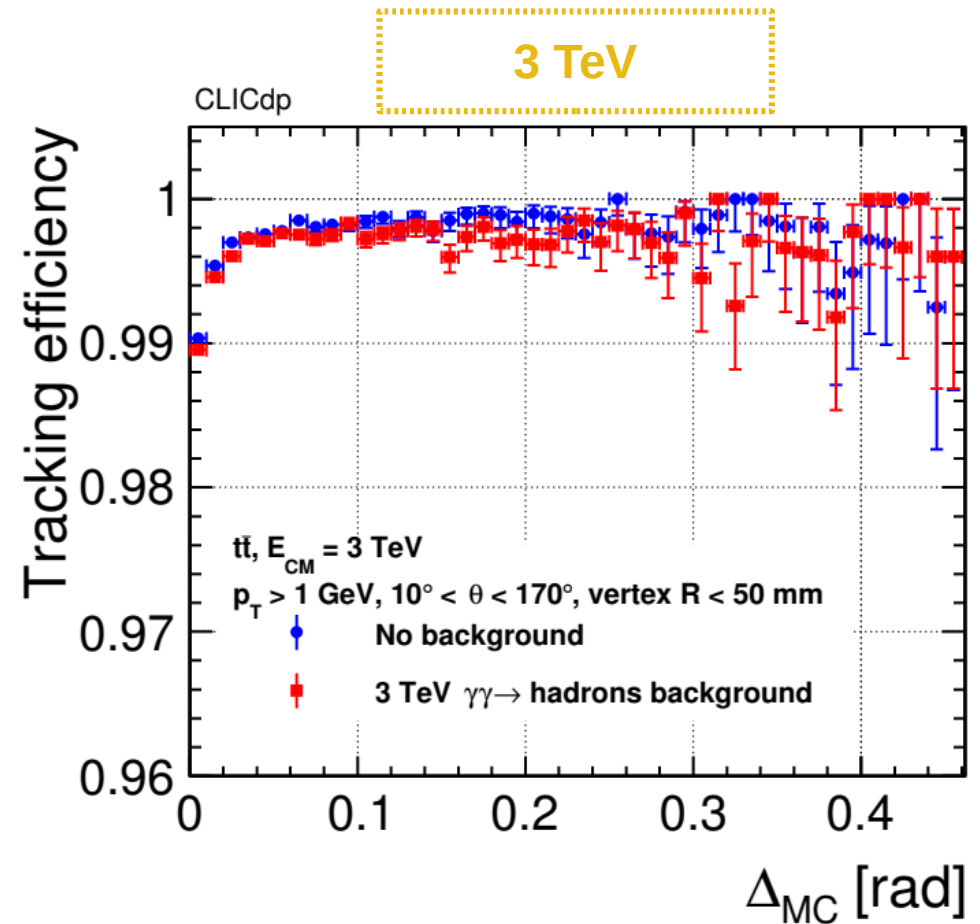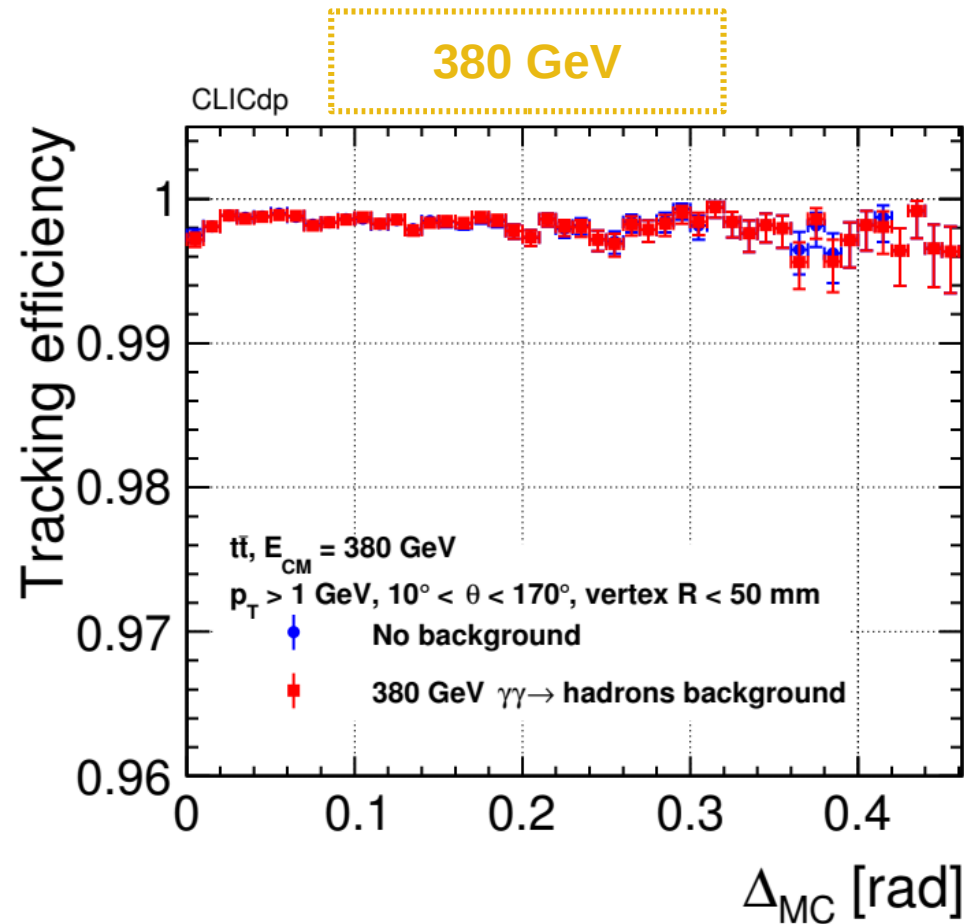- **Performance for isolated particles**

electrons

charged pions

- Electrons and pions are fully reconstructed as well

- Fake rate is very low, at the permille level

Some highlights

- **Performance for complex events**

- Efficiency > 98% in the entire tracker volume

- Fully efficiency for simulated MC particles with pT > 1 GeV and > 90% down to 200 MeV
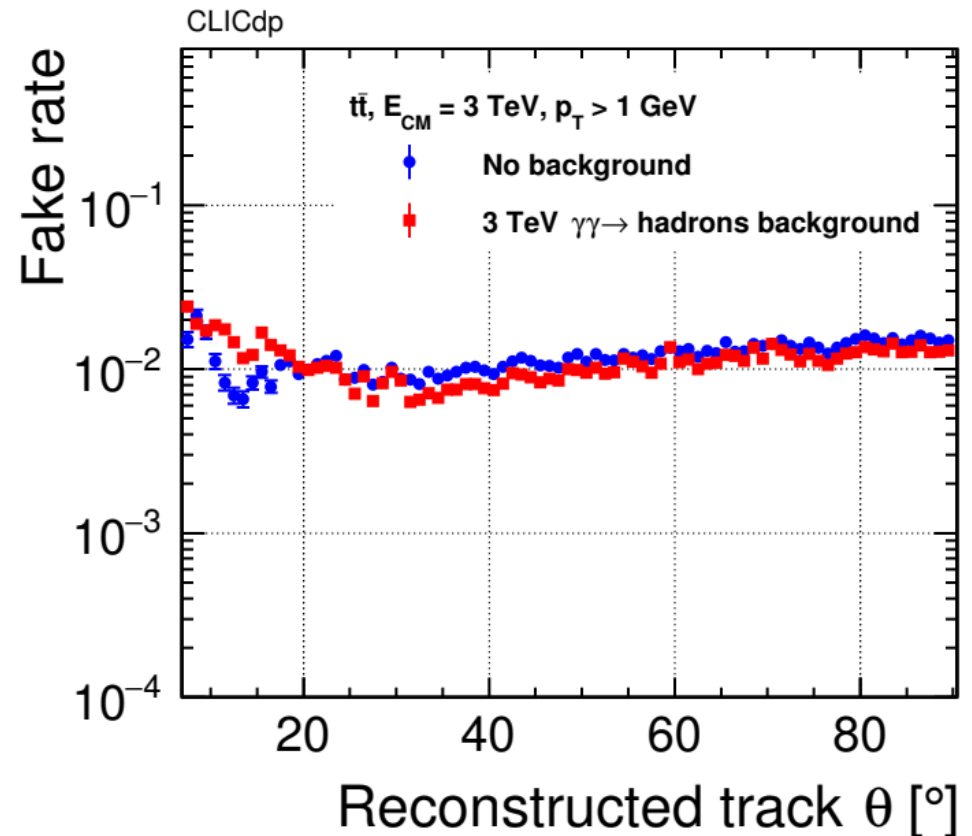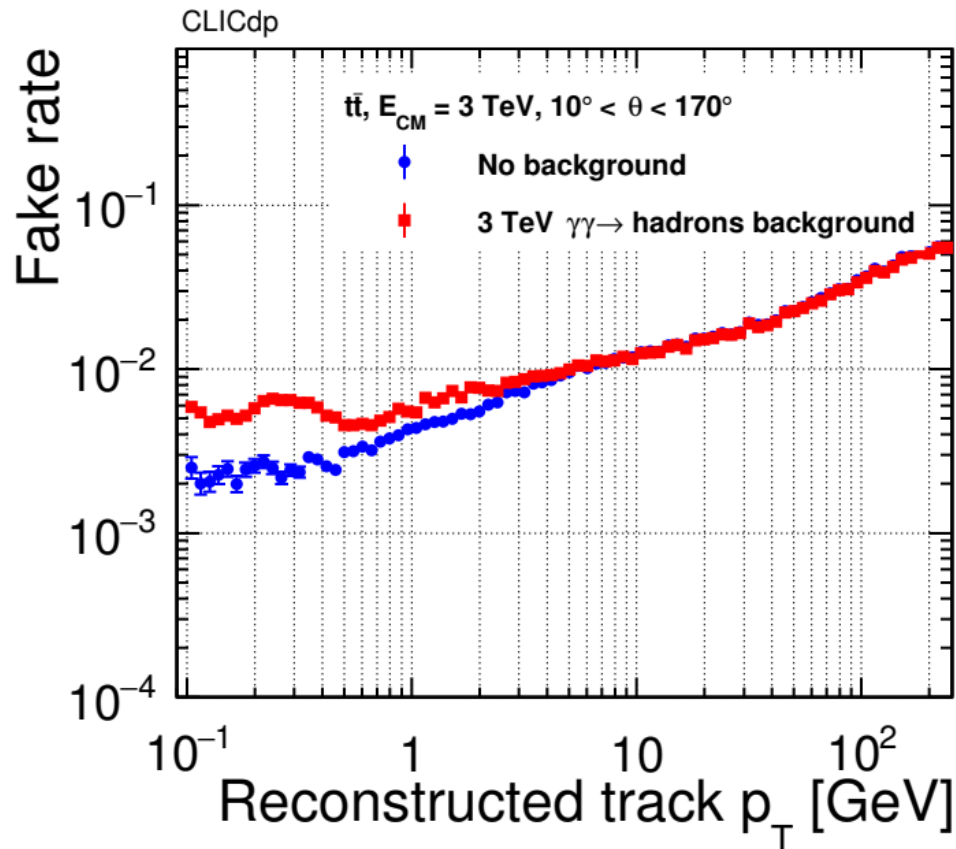
380 GeV

3 TeV

- Similarly efficient w/o and w/ overlay

- 1% inefficiency for very small distance between particles <u>even for high-pT jets</u>

Some highlights

- **Performance for complex events**

- New definition of fake rate

Fake rate = $\dfrac{\text{\#tracks with <75\% hits associated to the same MC particle}}{\text{reconstructed tracks}}$

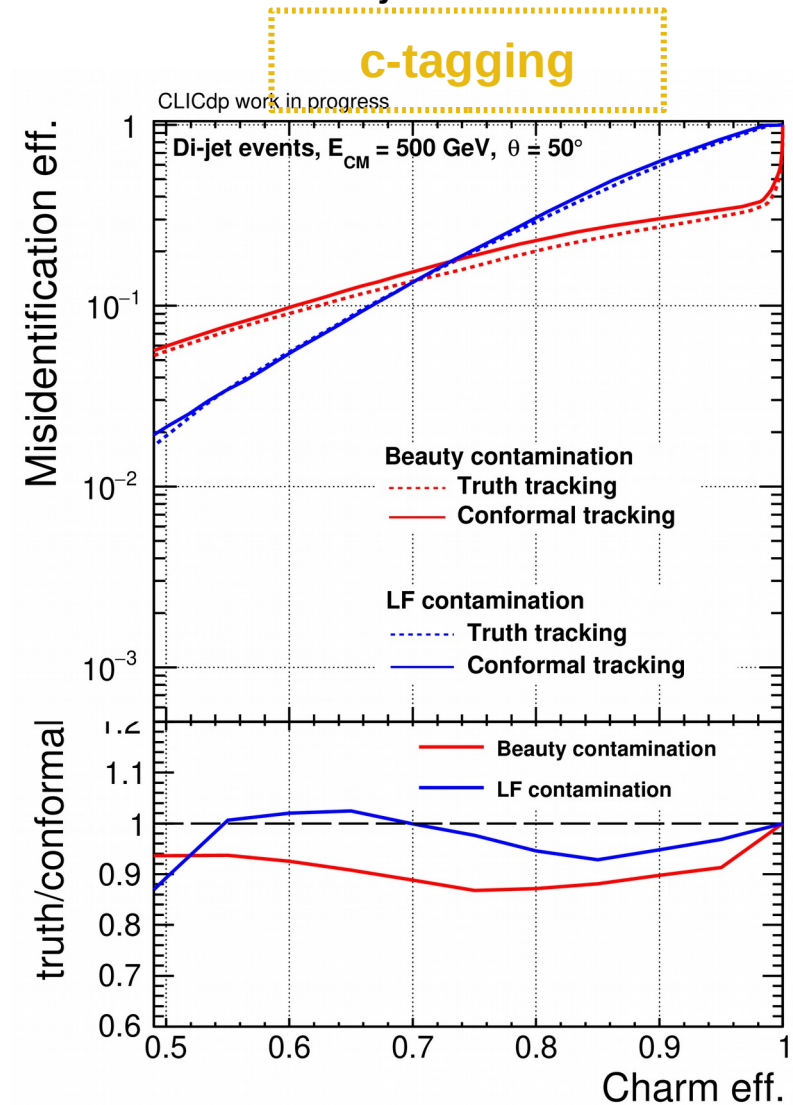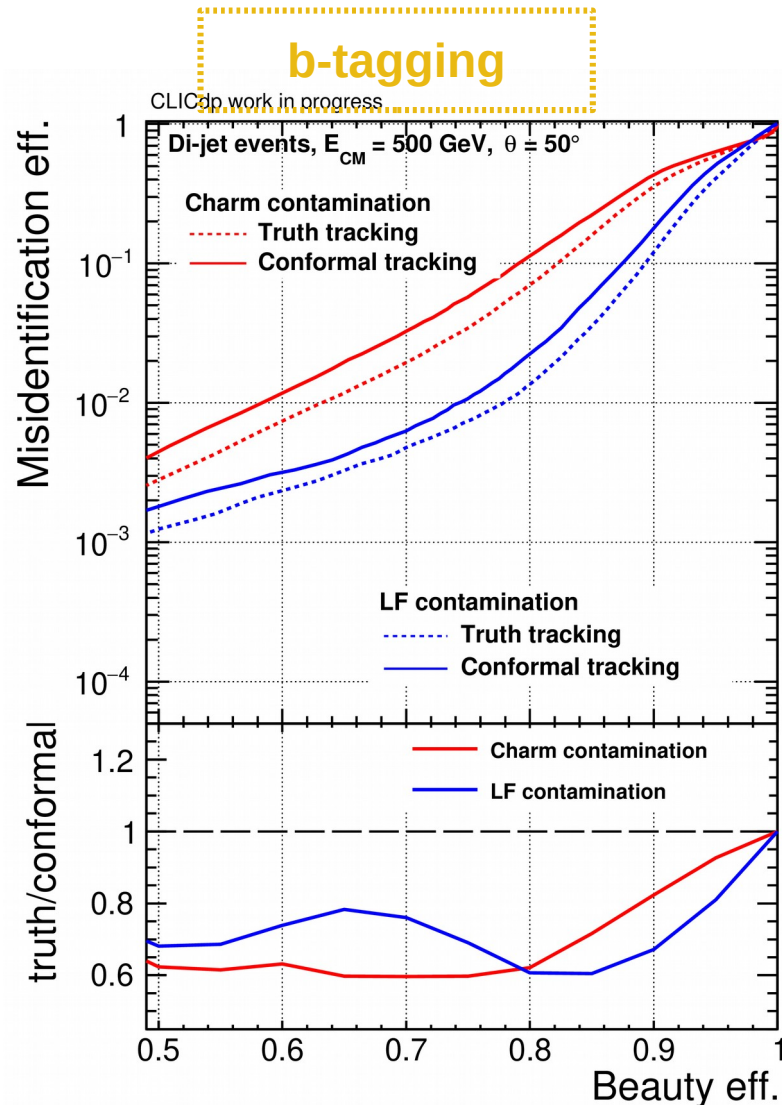
- Similar performance w/o and w/ overlay

- Fake rate about per-cent level

- Small increase for tracks with low pT

Flavour tagging

- Vertex finder reconstructs primary and secondary vertices

- Jet reconstruction using jet clustering algorithm

  → Feed information into MVA to establish the flavourness of each jet
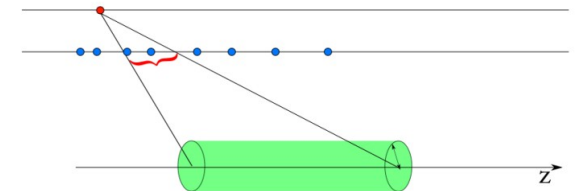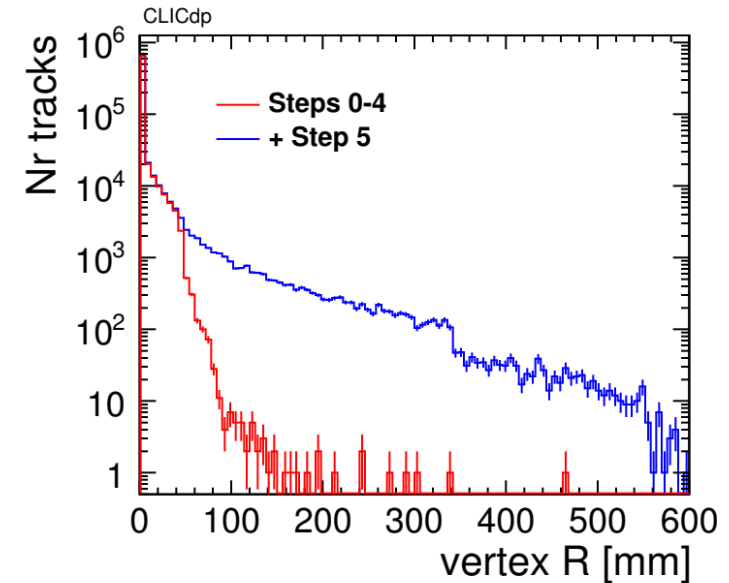
Can we do even better?

1) Time profile → reduced CPU time per event

Algorithm	Hit collection	Configuration
Build tracks	Vertex barrel	Standard cuts
Extend tracks	Vertex endcap	Standard cuts
Build tracks	Vertex	Looser cuts (angle x 5)
Build tracks	Vertex	Looser cuts (angle x 10; χ^2 x 20))
Extend tracks	Tracker	Looser cuts (angle x 10; χ^2 x 20)
Build tracks	Vertex + Tracker	Displaced cuts

+ Kalman Filter and smoother

- ~15 sec for complex events w/o overlay (90 tracks in average)

- ~554 sec for complex events w/o overlay (550 tracks in average)

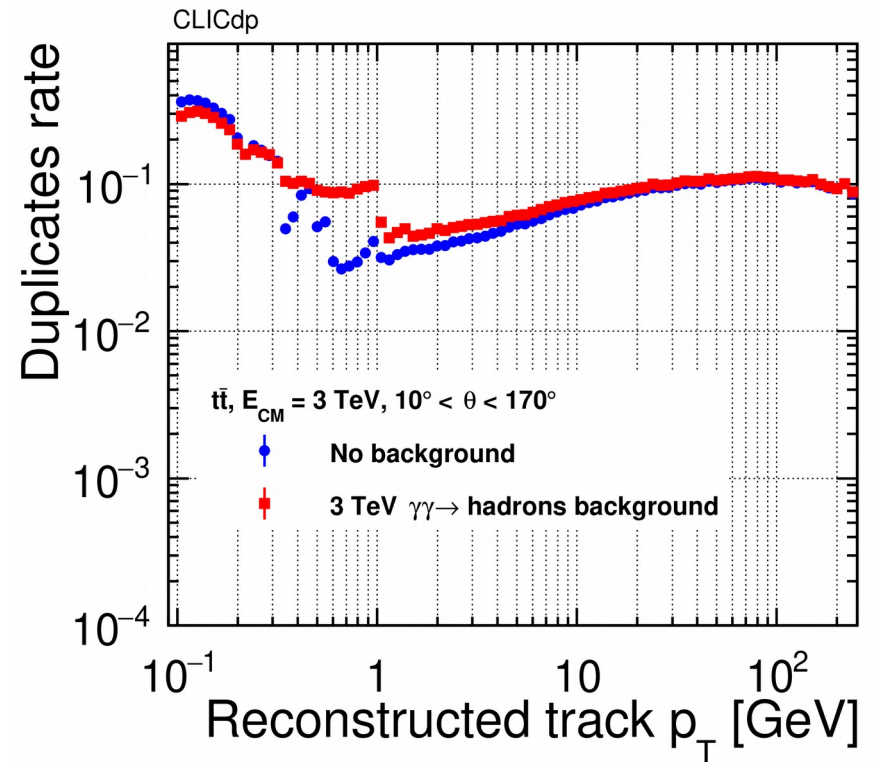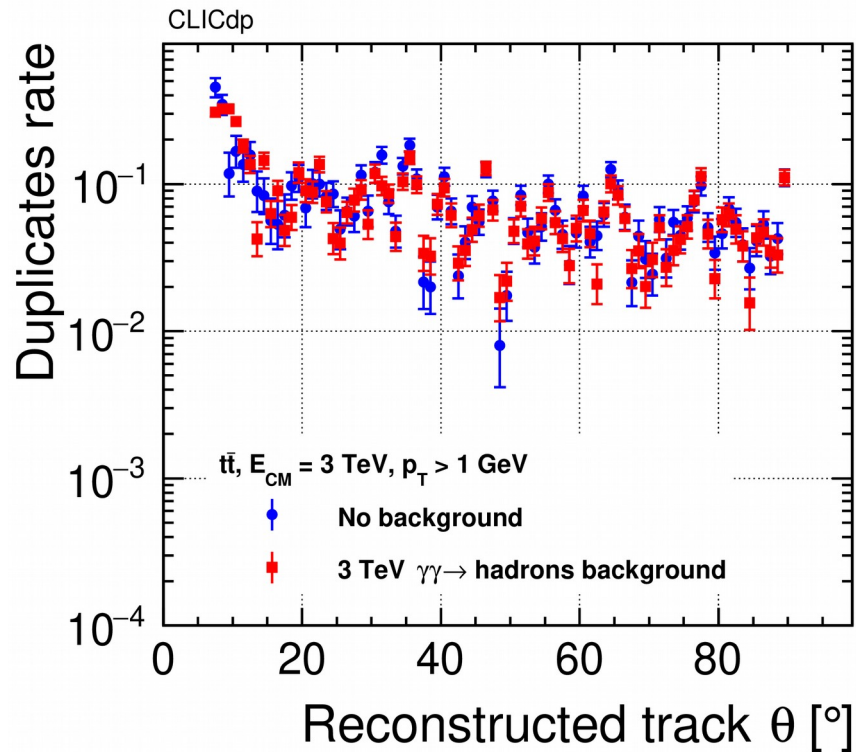 → mainly spent in building displaced tracks

- **Introduce a cut in longitudinal plane in seeding procedure**

  → **similar performance**

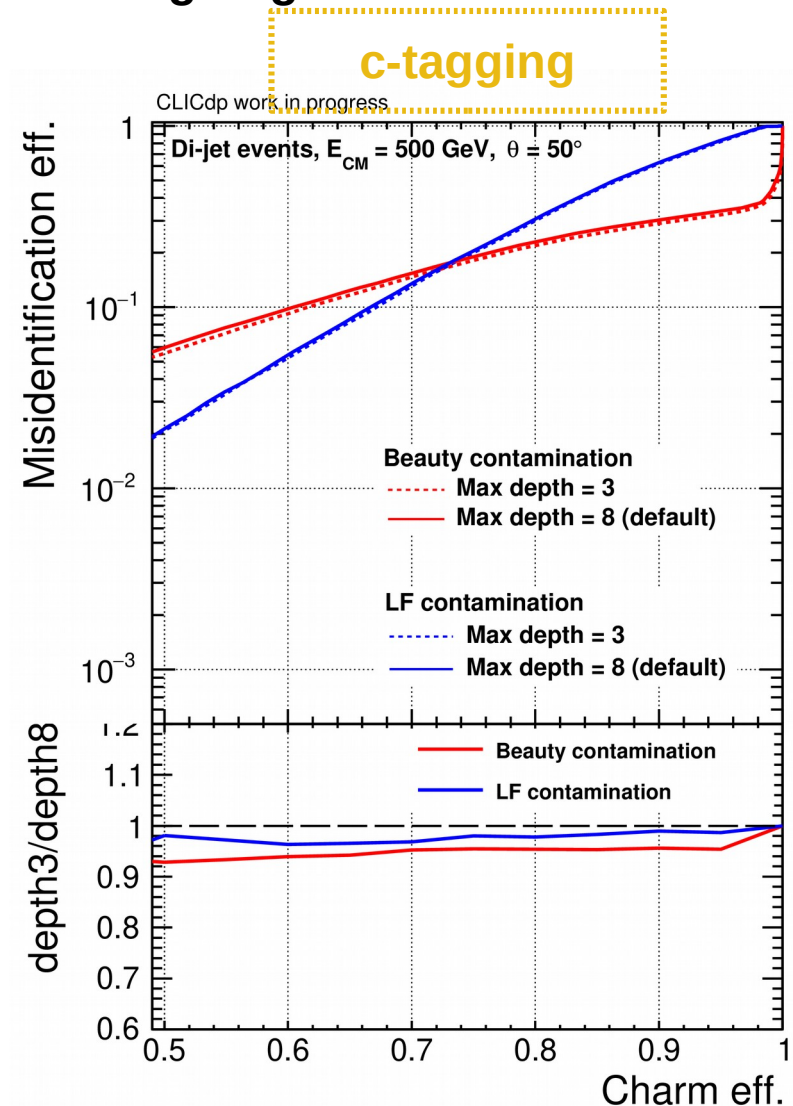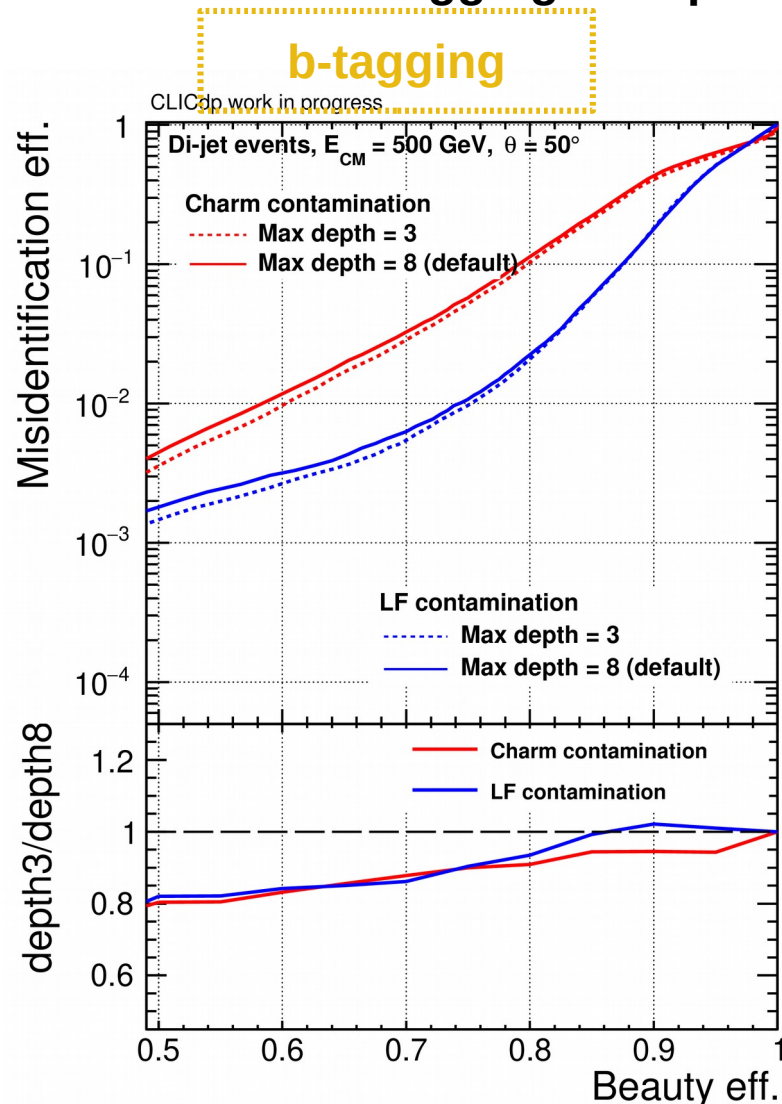 → **20-25% CPU time reduction**

Can we do even better?

1)Time profile → reduced CPU time per event

2)Duplicates study → on-going

- Duplicates: #reconstructed track associated to the same MC particle / total reco tracks

Can we do even better?

1) **Time profile → reduced CPU time per event**

2) **Duplicates study → on-going**

3) **Optimization flavour tagging MVA parameters → on-going**

Thank you for the attention!

arXiv:1908.00256

Beam-induced backgrounds

CLIC achieves high luminosities by using extremely small beam sizes

→ 3 TeV CLIC bunch size: $\sigma_{x,y,z}$ = {40 nm, 1 nm, 44 μm}

(at LHC $\sigma_{T,z}$ = {16.7 μm, 7.55 cm})

→ very high EM-fields → beam-beam interactions

Main backgrounds:

- **Incoherent e^+e^- pairs**

  → High occupancy

  → Mostly in the forward region

  → Impact on detector granularity and design

- **γγ → hadrons**

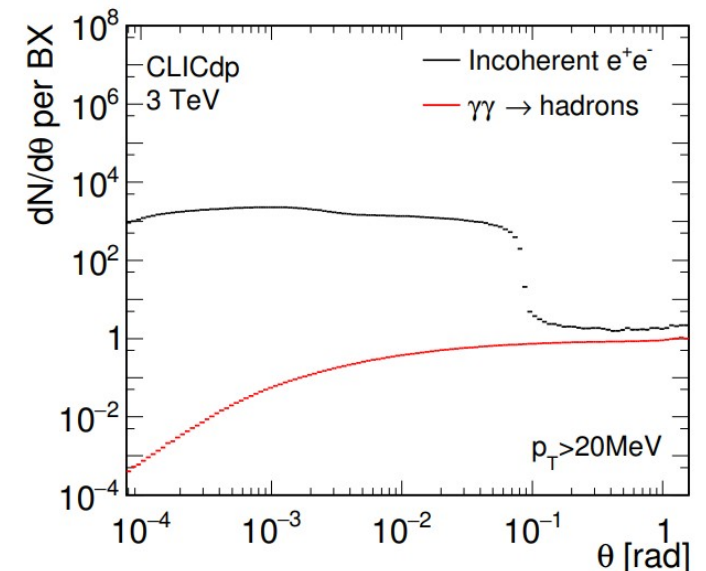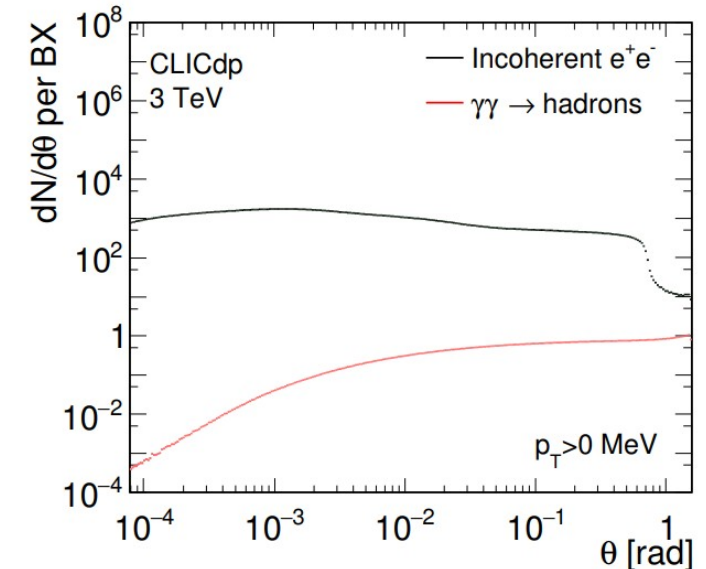 → High energy deposits

  → Impact on detector granularity, design

  and physics measurement

Detector acceptance starts at 10 mrad

Effect is dependent on √s

  → Background particles

  → Reduces √s

CLIC detector requirements

- **Momentum resolution**

  (e.g. H → $\mu^+\mu^-$, leptons from BSM processes)

  $$\sigma_{p_T}/p_T^2 \sim 2 \times 10^{-5} \text{ GeV}^{-1}$$

  above 100 GeV

- **Energy resolution for light-quark jets**

  (e.g. W/Z/h di-jet mass separation)

  $$\sigma_E/E \sim 3.5 - 5\%$$
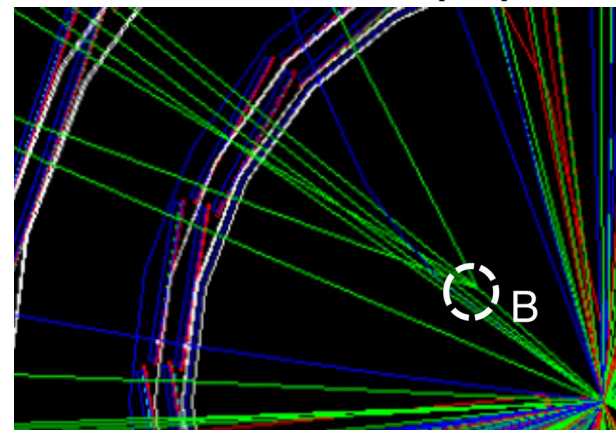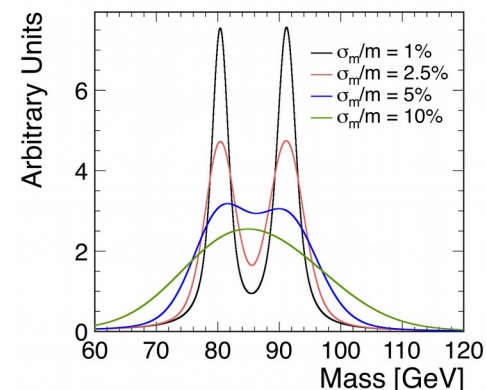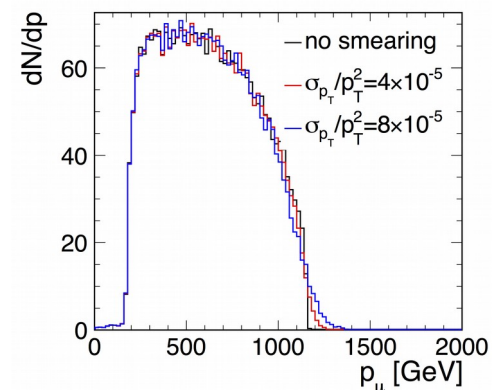
  for E = 1 TeV – 50 GeV

- **Impact parameter resolution**

  (e.g. b/c tagging, Higgs couplings)
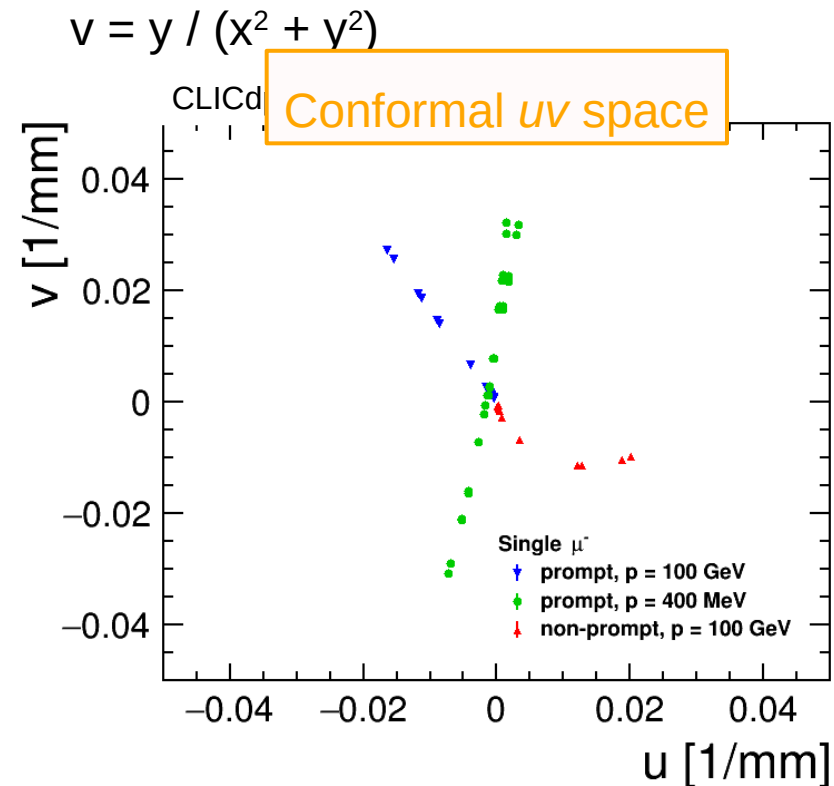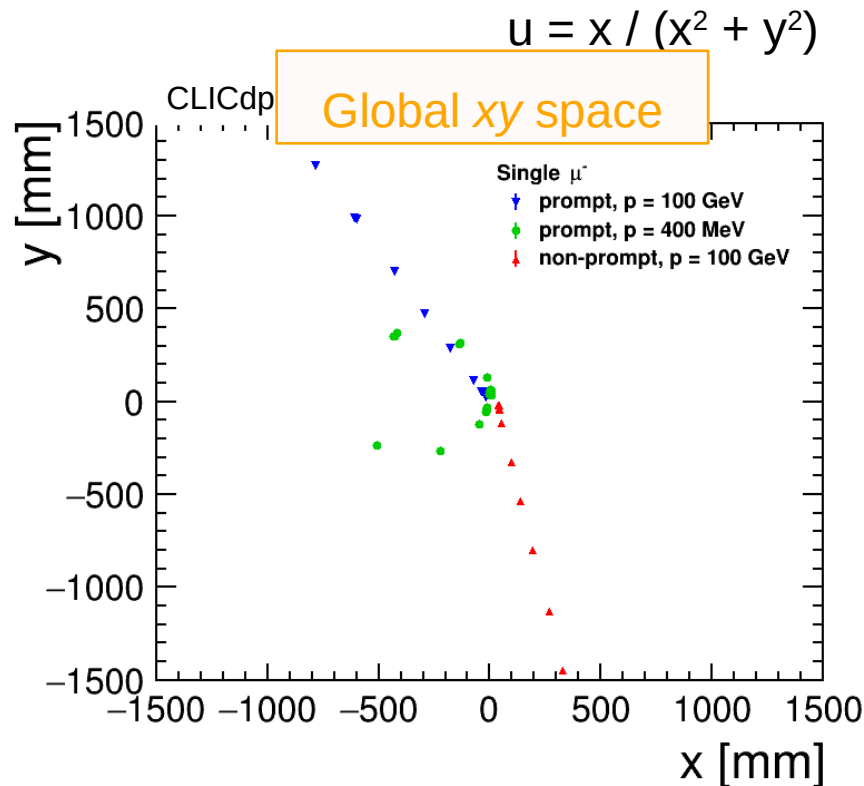
  $$\sigma_{r\varphi} = 5 \oplus 15 / (p[\text{GeV}] \sin^{3/2}\theta) \text{ μm}$$

$$e^+e^- \to \tilde{\mu}_R^+ \tilde{\mu}_R^- \to \mu^+ \mu^- \tilde{\chi}_1^0 \tilde{\chi}_1^0$$

Conformal Mapping

- The conformal mapping method is based on the fact that circles passing through the origin of a coordinate system xy can be translated onto straight lines in a new coordinate system uv

$$u = x / (x^2 + y^2) \qquad v = y / (x^2 + y^2)$$
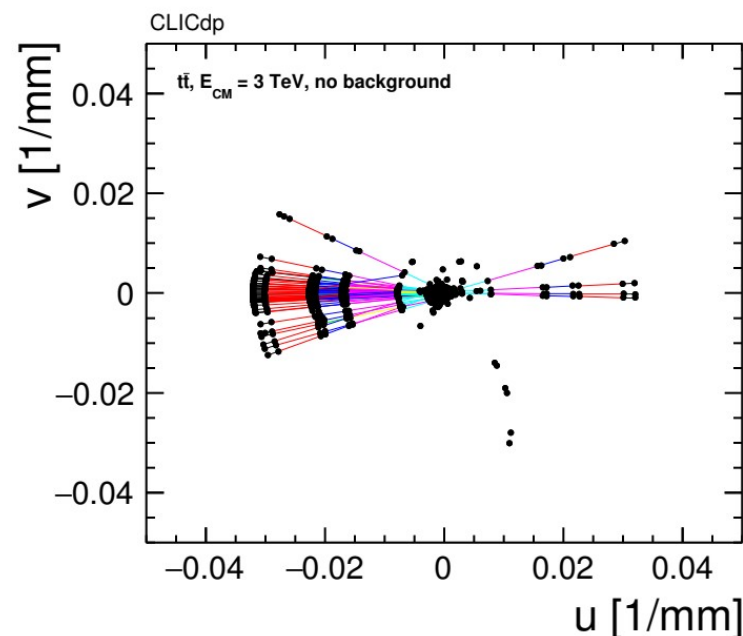

Global *xy* space

Conformal *uv* space

- Innermost hits in *uv* are in Silicon Tracker, outermost hits are in Vertex Detector
- Only straight lines search not enough
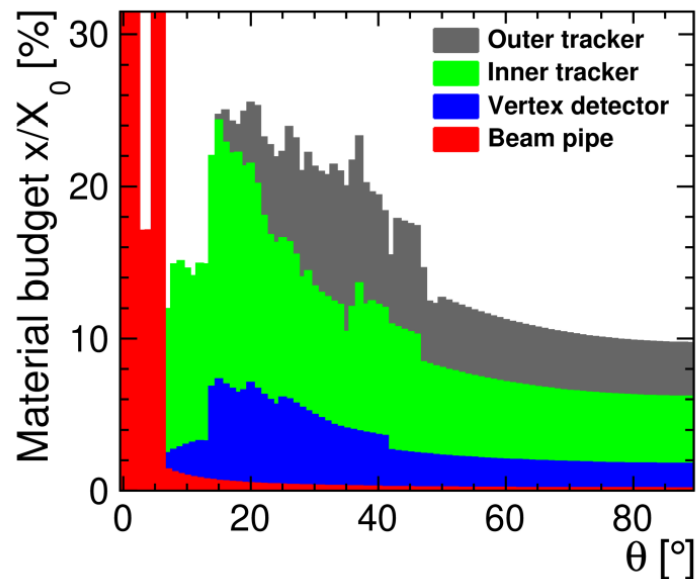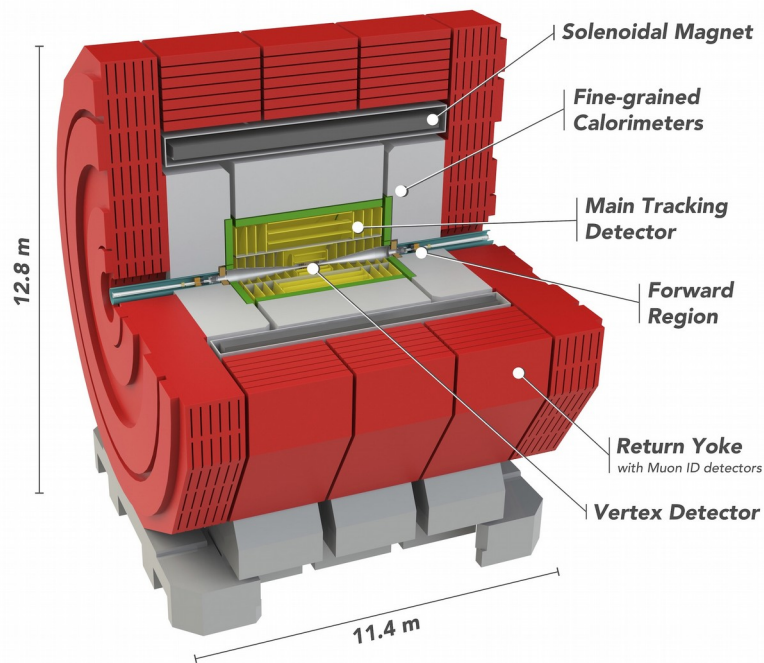 - → Pattern recognition in conformal space via cellular automaton

ConformalTracking in CLICdet

Algorithm	Hit collection	Configuration
Build tracks	Vertex barrel	Standard cuts
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Build tracks	Vertex	Looser cuts (angle x 5)
Build tracks	Vertex	Looser cuts (angle x 10; χ^2 x 20))
Extend tracks	Tracker	Looser cuts (angle x 10; χ^2 x 20)
Build tracks	Vertex + Tracker	Displaced cuts

- **5 steps targeting prompt-tracks:**
  - from vertex detector to silicon tracker
  - min number of hits = 4
  - standard or looser (angle or χ^2) cuts
- **1 step targeting displaced tracks:**
  - quadratic terms in the CT fit added
  - inverted order search: from silicon tracker to vertex detector
  - broader search angle than for prompt tracks
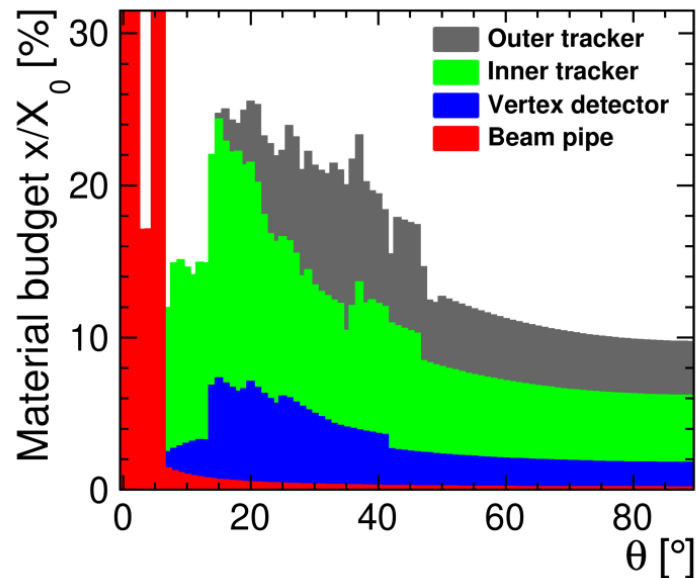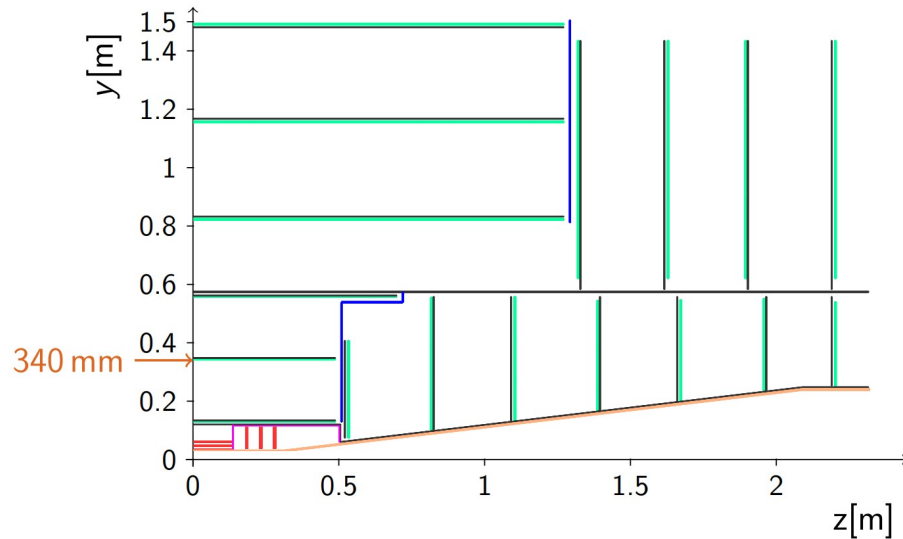 - min number of hits = 5

CLICdet tracker

- **Superconducting solenoid** with 4T magnetic field

- **Vertex Detector**

  - 3 double layers with 25 × 25 μm^2 pixels

  - Air cooling

  - Extremely accurate and light:

    single point resolution = 3 μm

    material budget < 0.2 % X_0 per layer

- **Silicon Tracker**

  - Tracker composed of large pixels/strips

  - Outer radius ~ 1.5 m

  - Single point resolution = 7 μm × 90 μm

  - Material budget:

    Detector: ~1% X_0 per layer

    Support & cables: ~2.5% X_0

  - Precise timing for background rejection:

    < 10 ns hit time-stamping in tracking

- **Full simulation with DD4hep geometry**

CLICdet tracker

- **Superconducting solenoid** with 4T magnetic field

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- **Full simulation with DD4hep geometry**

Performance for isolated muons

- Track parameters resolution of isolated muons
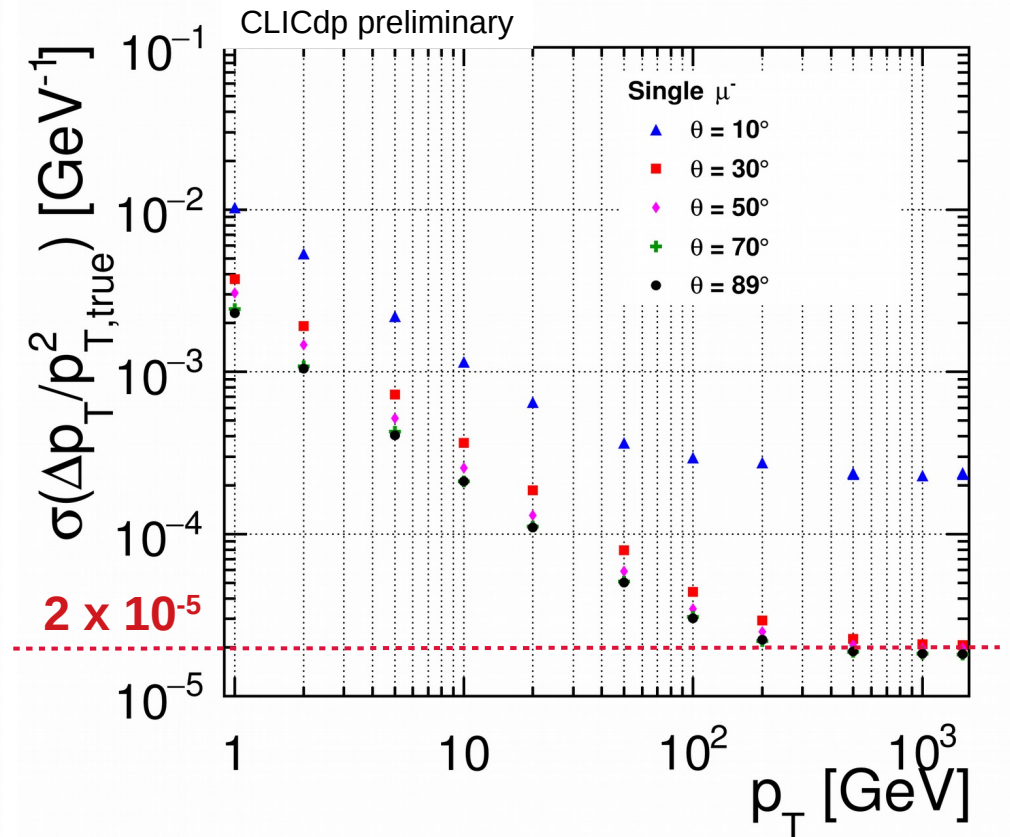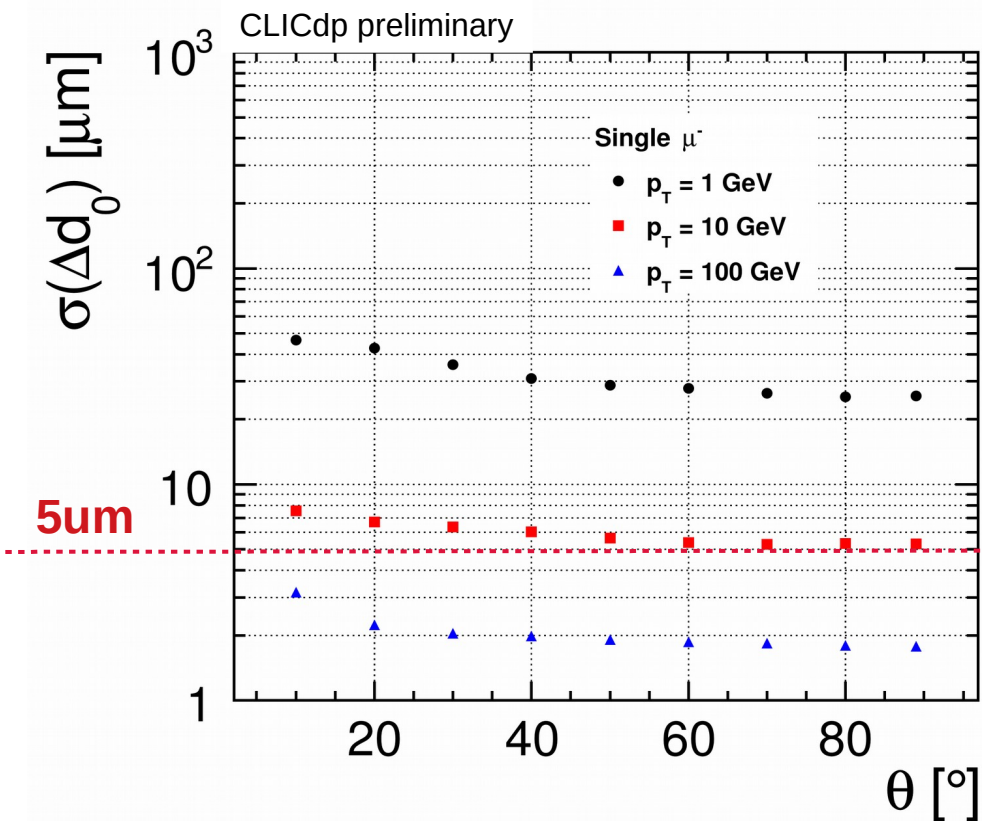
- Very good agreement with target values of required performance