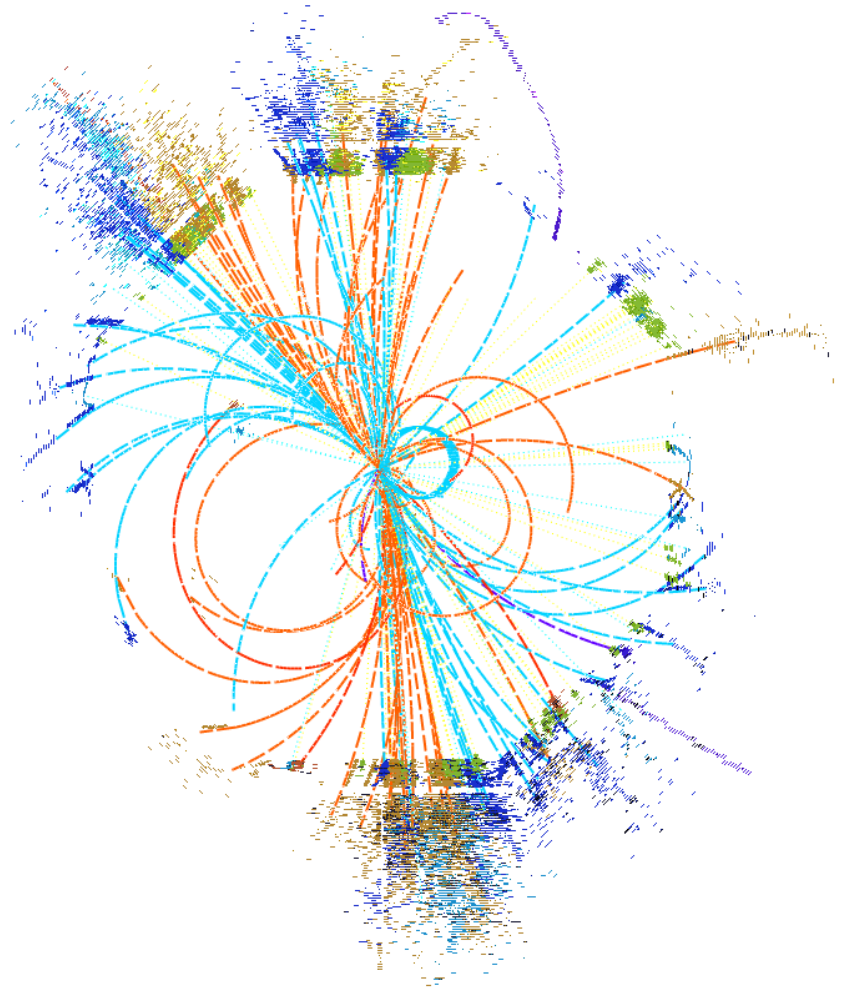# CLIC vertex and tracking system: What does the physics need?
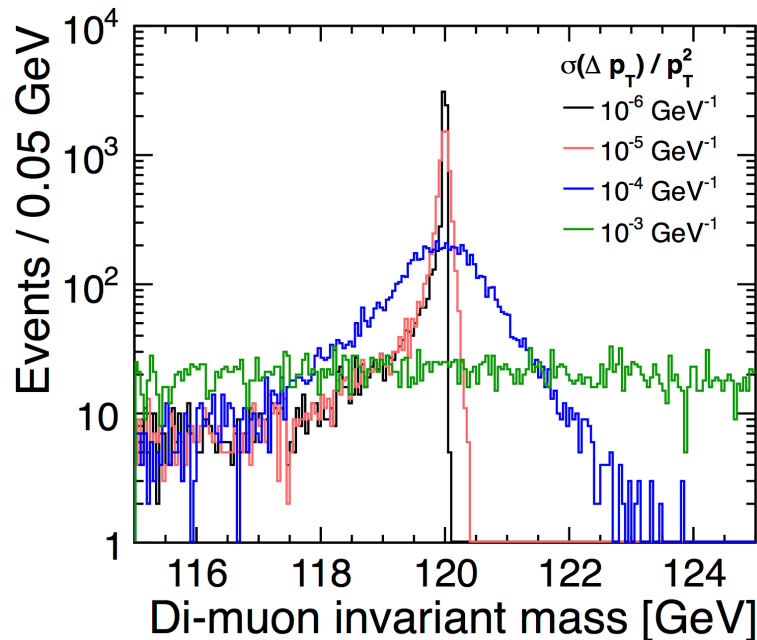
Philipp Roloff (CERN)

CLICdp meeting, LCWS15, Whistler, Canada, 05/11/2015

Tracking: momentum resolution

$$\frac{\sigma(p_T)}{p_T^2} \sim 2 \times 10^{-5}\,GeV^{-1}$$

Lepton from BSM processes:

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

H → μ⁺μ⁻ at 3 TeV

Higgs width (≈ 4 MeV) negligible
compared to tracking resolution
→ similar for other narrow resonances
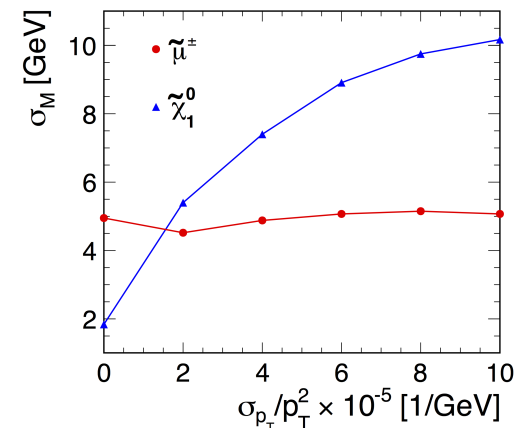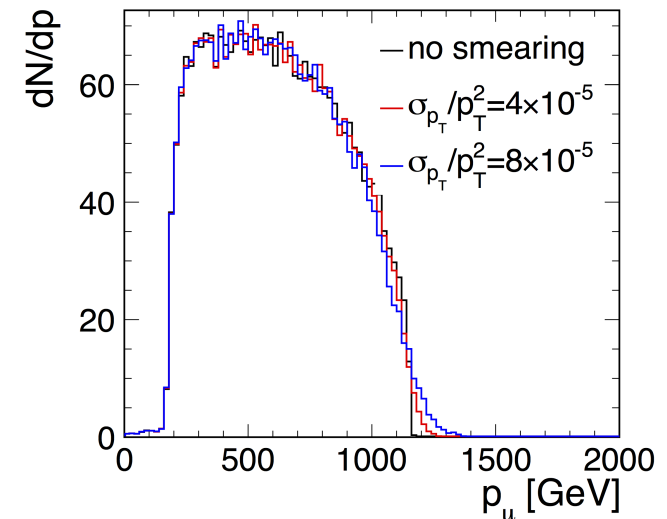
Flavour tagging performance

- The aim is to have the best possible beauty and charm identification capabilities in the entire detector

- Depends on many aspects: vertex and tracking detector hit resolutions, geometry and material budget of the inner layers, particle ID, …

- One important aspect: impact parameter resolution

$$\sigma(d_0) = \sqrt{a^2 + b^2 \cdot GeV^2 / (p^2 \sin^3\theta)} , \quad \boxed{a \approx 5\,\mu m} , \boxed{b \approx 10 - 15\,\mu m}$$

                hit resolution   **multiple scattering**

- Looking here at two particular challenging cases:

  - Forward direction
  - Very high-energetic jets

- Also relevant: vertex charge (e.g for A_{FB}^b and A_{FB}^t)
→ needs more study

The forward region

• The forward direction becomes increasingly important at high energy

• Example: double Higgs production (important argument for high-energy CLIC operation)

• Significant reduction of performance observed in the forward (also for jet reconstruction)

• Some improvement might be possible by refined reconstruction tools (could be part of SW development for new detector model)

**Higgs polar angle in $e^+e^- \rightarrow HH\nu\bar{\nu}$ events**

spirals: 200 GeV dijets

100 GeV jets
CLIC_SiD

spirals: 200 GeV dijets
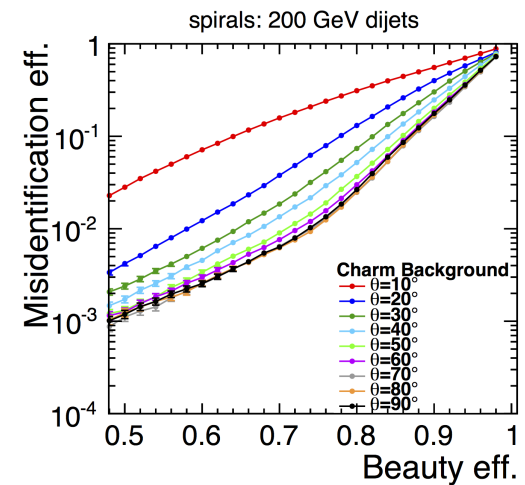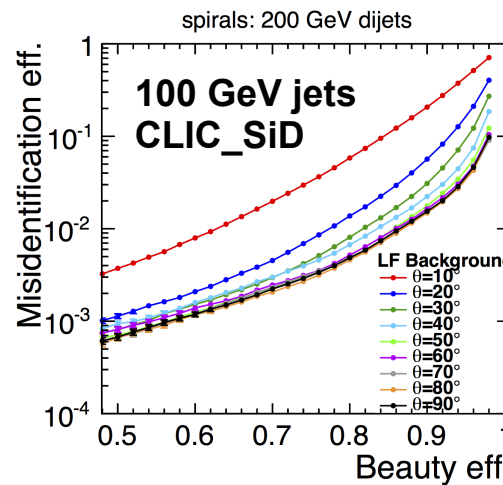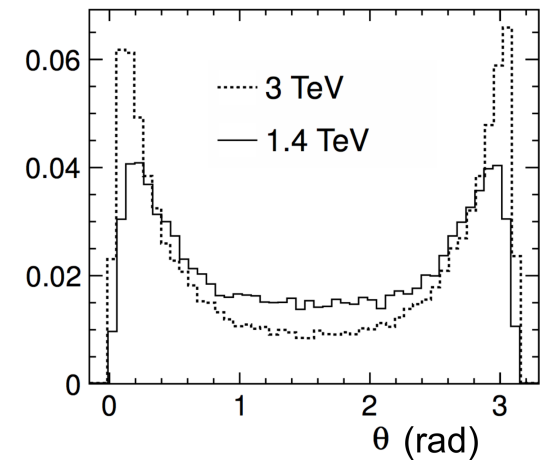
CLICdp-Note-2014-002

Impact on a physics study

Measurement of
$\sigma(e^+e^- \to \nu\bar{\nu}H)$ x BR(H $\to$ b$\bar{\text{b}}$/c$\bar{\text{c}}$) at 3 TeV:

Demonstrating impact of
±20% changes in the fake rates for
the charm and beauty tagging
(increases or decreases the number of
background events passing the selections)

$\to$ 6-7% effect on precision for H $\to$ b$\bar{\text{b}}$
$\to$ 15% effect on precision for H $\to$ c$\bar{\text{c}}$
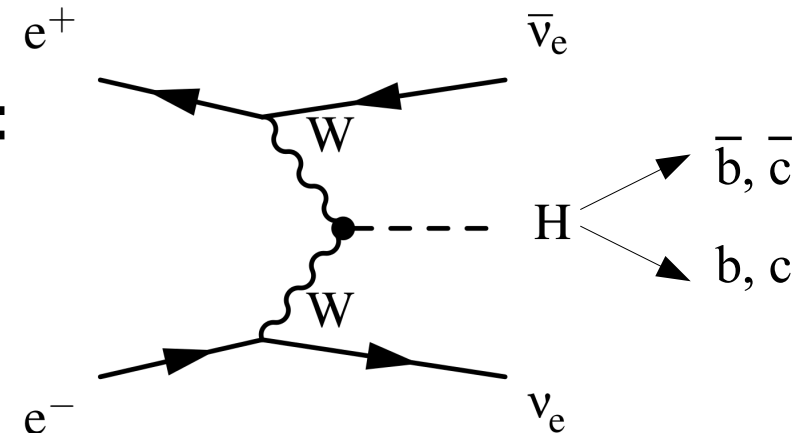
CLICdp-Note-2014-002

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

Beauty jets at high energy

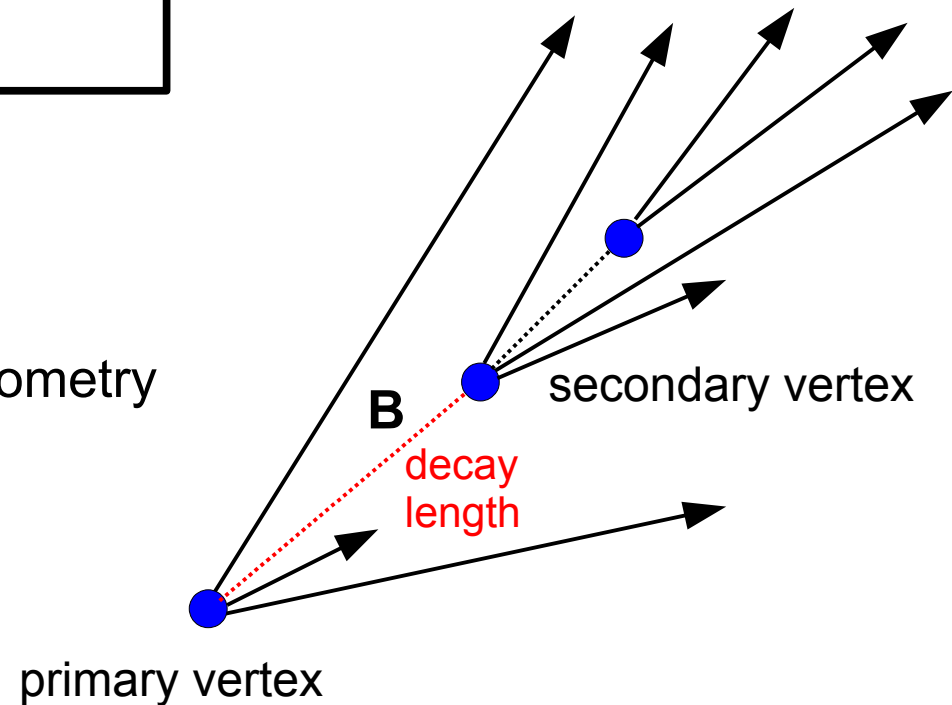• Beauty quark identification for high energetic jets crucial
for BSM physics at, examples:

- $e^+e^- \to b\bar{b}$, e.g. to discriminate Z' scenarios
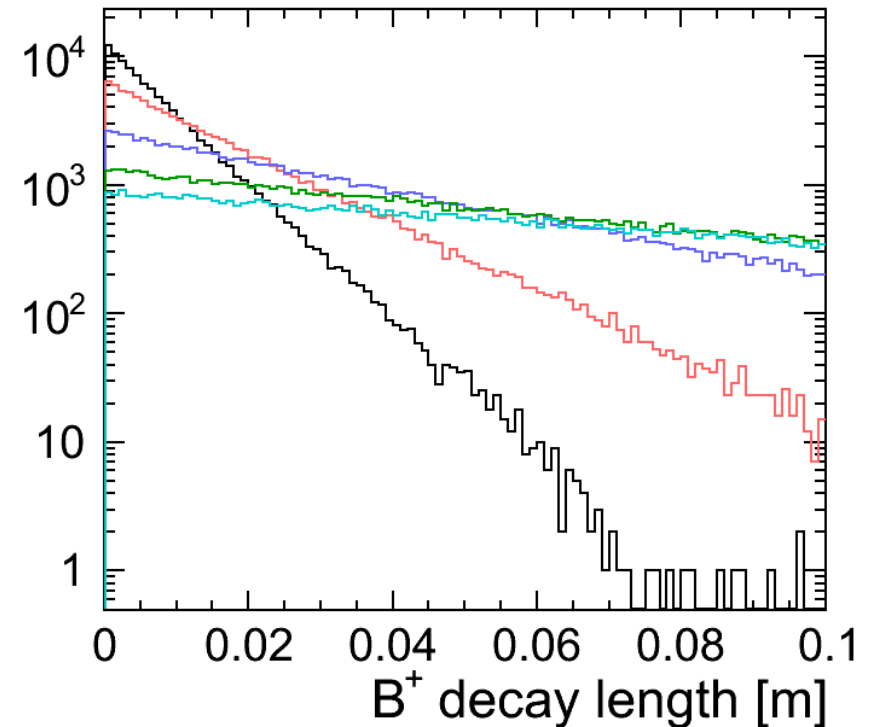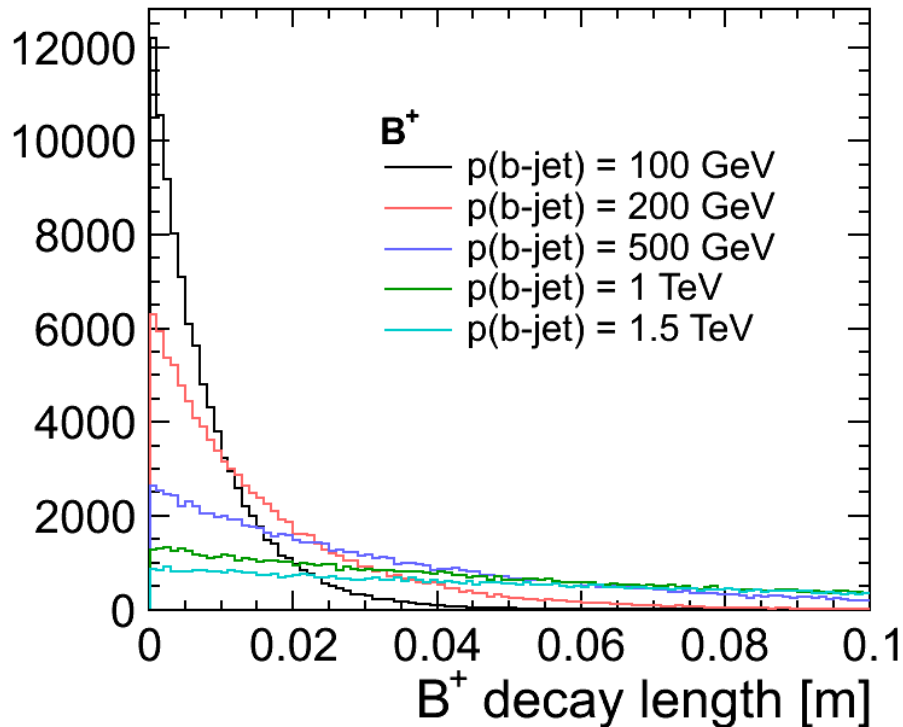- sbottom decays
- H/A → bb, $H^\pm \to$ bt (CDR Vol. 2)
- ...

• Highly boosted beauty hadrons decay
after several cm

• Consequences for the barrel detector geometry
illustrated on the next few pages

$f(b \to B^+) \approx 40\%$, т = 1.64 • 10^{-12} s
$f(b \to B^0) \approx 40\%$, т = 1.52 • 10^{-12} s
$f(b \to B_s) \approx 10\%$, т = 1.51 • 10^{-12} s

B   secondary vertex

decay
length

primary vertex

B⁺ decay length

- Similar distributions for B^0 and B_s
- Need to reconstruct B decay vertices or at least precisely measure the impact parameters of the B decay products

B⁺: comparison to barrel radii

CLICdet_2015 (currently):
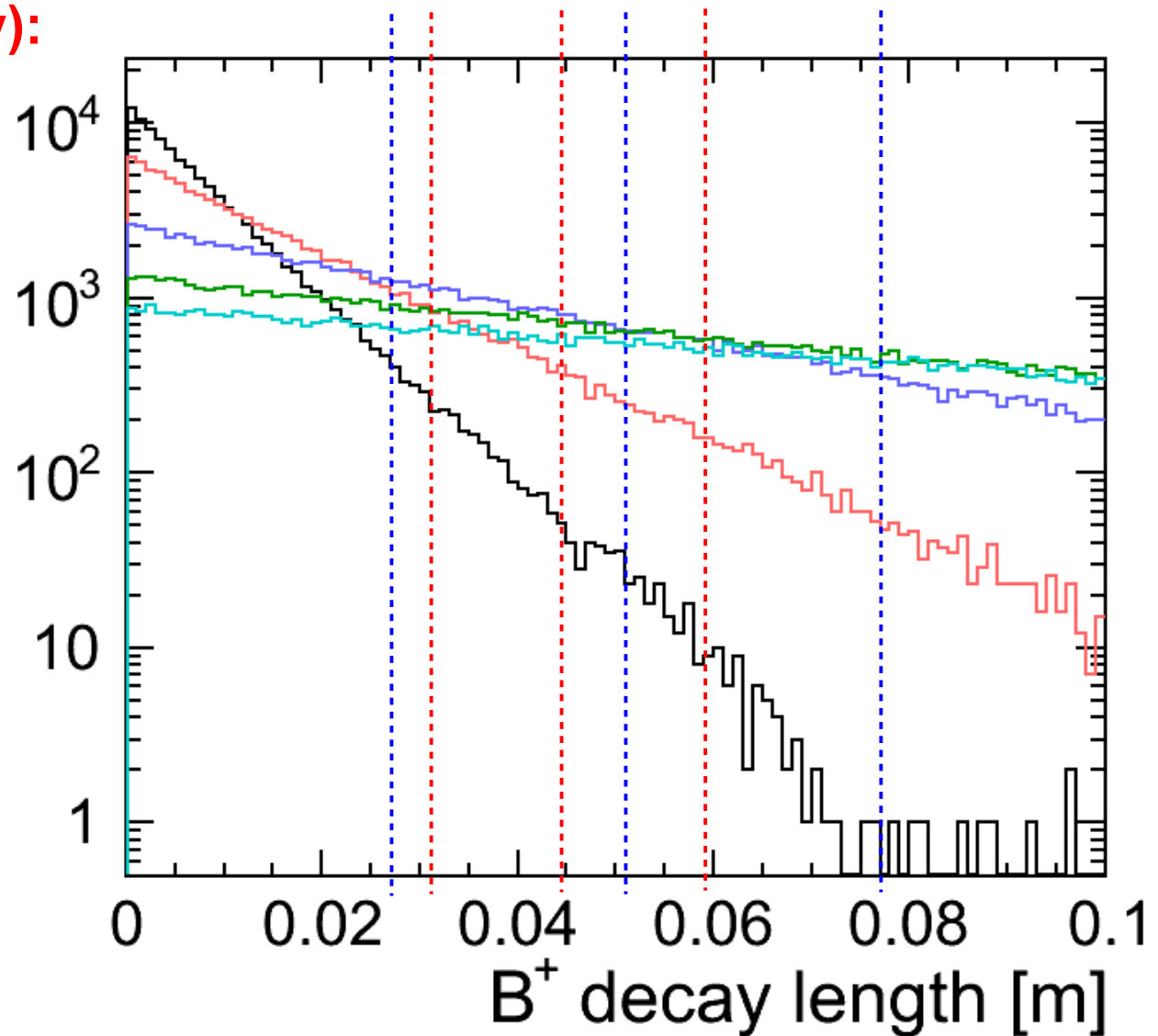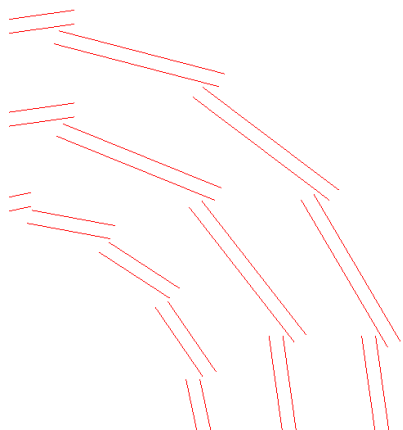
R_1 = 32 mm

R_2 = 45 mm

R_3 = 59 mm

CLICdp-2014-002:

R_1 = 27 mm

R_2 = 51 mm

R_3 = 77 mm

B⁺ decays for jets at θ = 90°

CLICdet_2015:

Before layer	100 GeV	200 GeV	500 GeV	1 TeV	1.5 TeV
1	98.0%	86.4%	55.9%	33.8%	24.2%
2	99.6%	93.7%	68.1%	44.1%	32.2%
3	99.9%	97.3%	77.4%	53.0%	39.9%

CLICdp-Note-2014-002:

Before layer	100 GeV	200 GeV	500 GeV	1 TeV	1.5 TeV
1	96.4%	81.6%	50.0%	29.5%	20.9%
2	99.8%	95.7%	72.5%	48.1%	35.6%
3	100.0%	99.2%	85.6%	62.4%	48.3%

Summary and conclusions

- Momentum resolution requirement:
$\sigma(p_T) / p_T^2 \approx 2 \times 10^{-5}$ GeV^{-1}

- Forward flavour tagging crucial for at high energy

- B hadrons in beauty jets at high energy decay after several cm in the detector

Fragmentation

Fragmentation fractions (simplified):

$f(b \to B^+) \approx$ 40%, $\tau = 1.64 \cdot 10^{-12}$ s

$f(b \to B^0) \approx$ 40%, $\tau = 1.52 \cdot 10^{-12}$ s

$f(b \to B_s) \approx 10\%$, $\tau = 1.51 \cdot 10^{-12}$ s

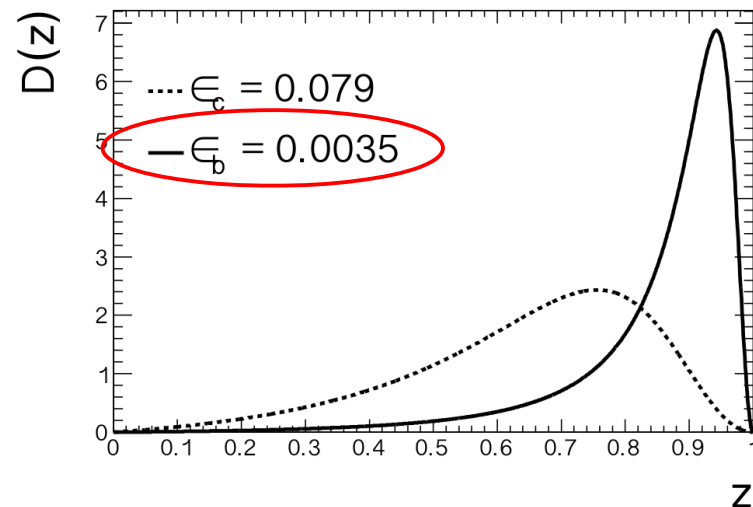$f(b \to$ baryons$) \approx 10\% \to$ neglected here

Fragmentation function:
Typically 80% of b-jet energy
taken by B hadron

Peterson:
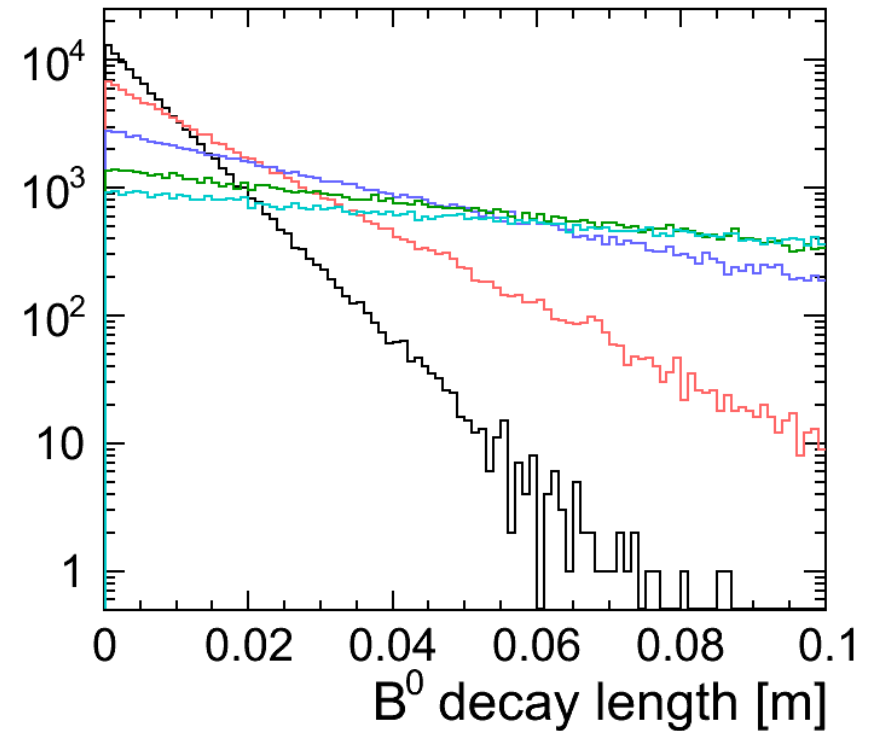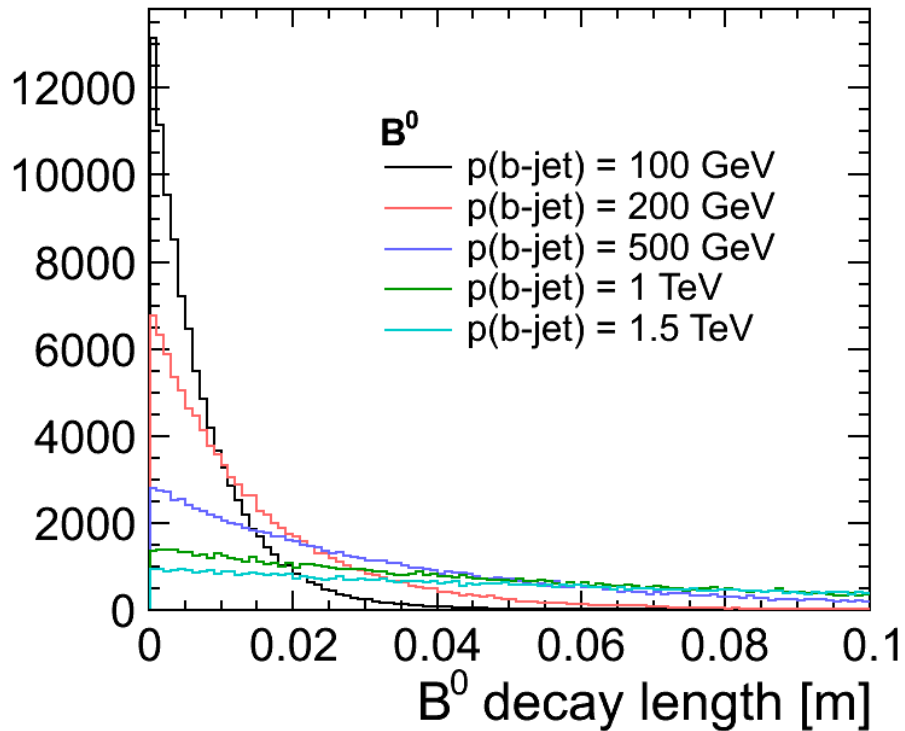$D(z) \sim 1 / (z[1-1/z-\varepsilon/(1-z)]^2)$
$\varepsilon =$ 0.0035 (common choice for beauty)
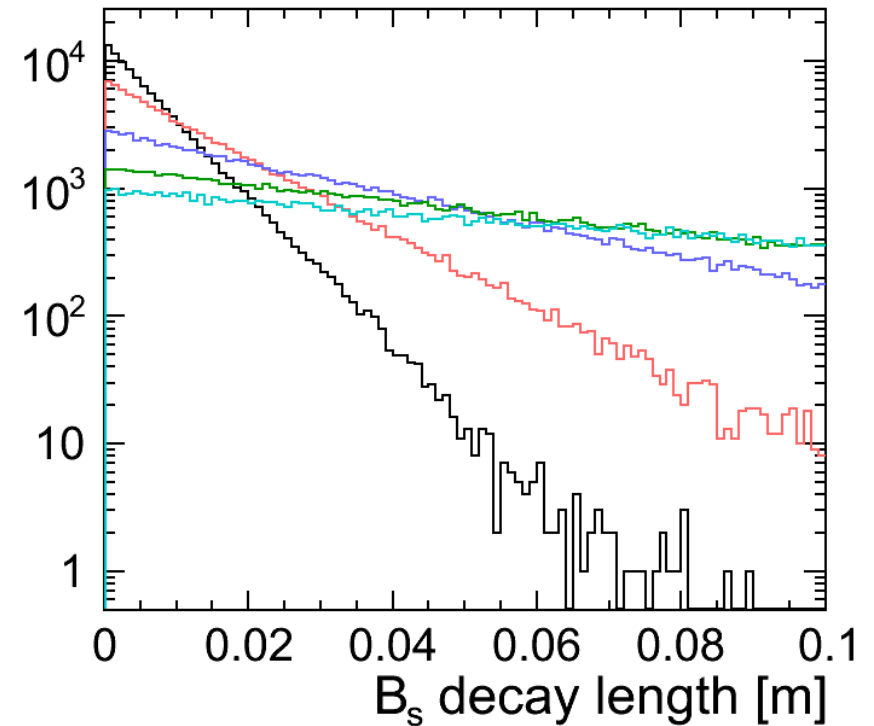z: fraction of b-momentum transferred to the hadron
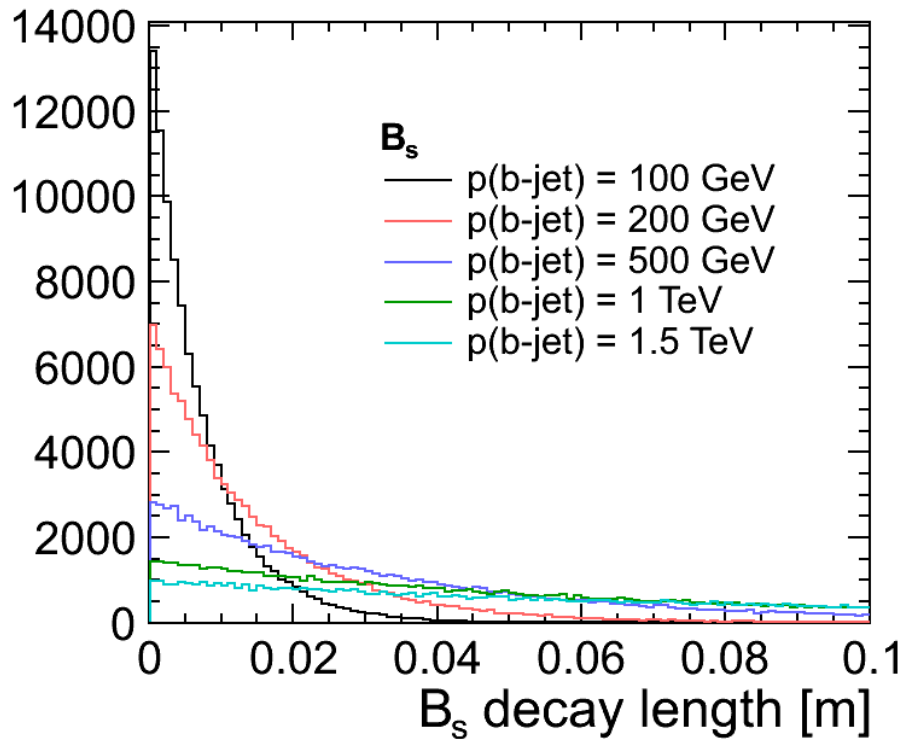

The rest is basic physics: $\tau_{lab} = \gamma\tau$, $N(t) = N_0 \cdot \exp(-t/\tau_{lab})$

B⁰ decay length


Similar to B^+ and B_s

B$_s$ decay length

Similar to B$^+$ and B^0

Flavour tagging at CLIC

Based on the LCFIPlus package:
(arXiv:1506.08371)
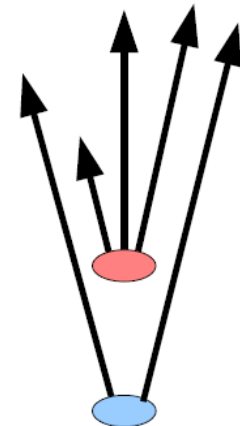
• Jets grouped into 4 categories

• 2 classifiers trained for each category: b-tag, c-tag

• In the following, using only tracking and vertexing information

• Performance can be improved using lepton ID, but not relevant for vertex geometry optimisation
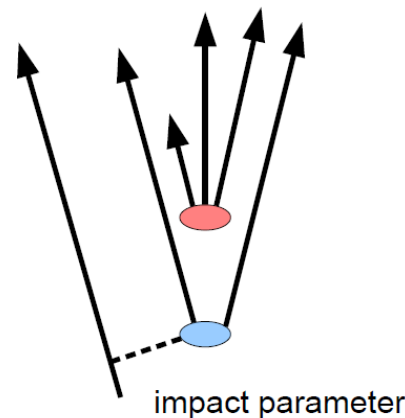

no vertex
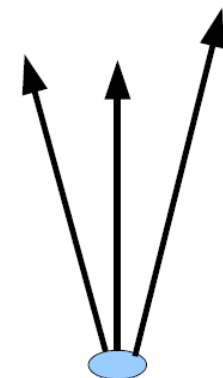
primary vertex

one vertex

one vertex + pseudovertex

impact parameter

two vertices