CLIC vertex and tracking system: input from detector optimisation studies

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CLICdp meeting
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Whistler

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Outline

- Constraints from backgrounds:

  Inner radius, beam pipe, forward acceptance; cell sizes

- Vertex-detector layout optimisation

- Tracker layout optimisation

- Proposal for future studies

Inner radius, beam pipe, fwd acceptance

- High rate of forward-peaked background events, mostly e^+e^- pairs

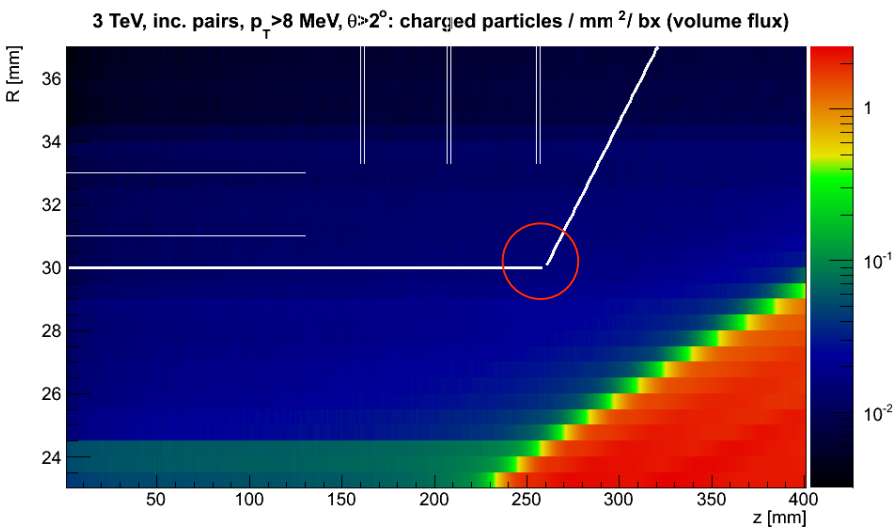
→ constrains inner radius of vertex detector
  - R_i~31 mm (~3% train occupancy for B=4 T and √s=3 TeV)

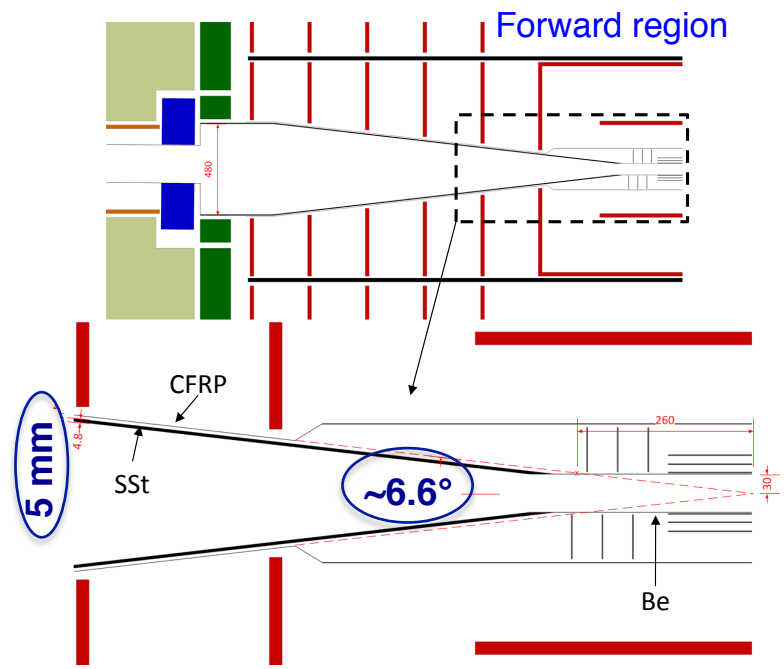
→ constrains beam pipe layout:
  - conical forward region pointing towards interaction point
  - thick steel sections to absorb back-scattered particles

→ constrains forward acceptance (with LumiCal acceptance and air cooling constraints)
  - θ_{min}~7°

- *These appear to be rather hard constraints leaving not much room for improvement, unless we find another way to reduce back-scatters (w/o the thick beam pipe pointing to IP)*

Direct hits from incoherent pairs in CLIC_ILD_CDR

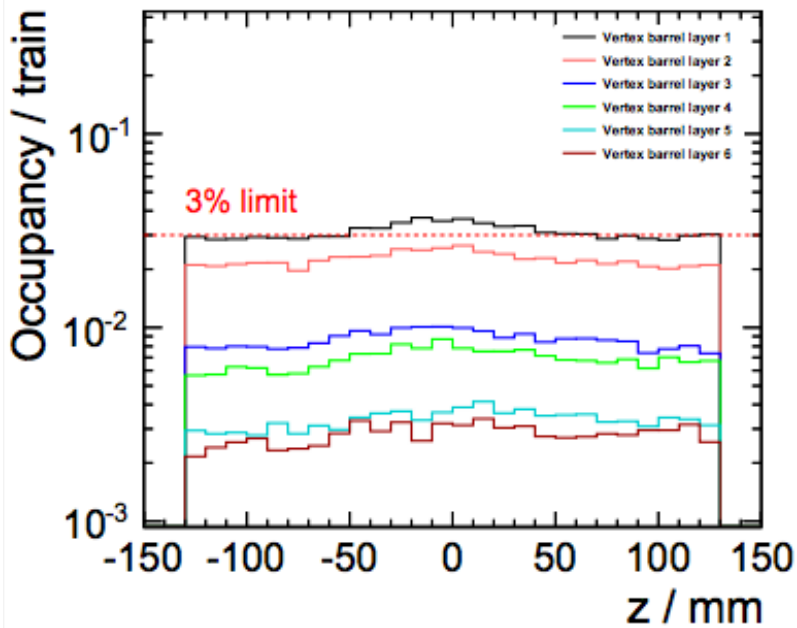




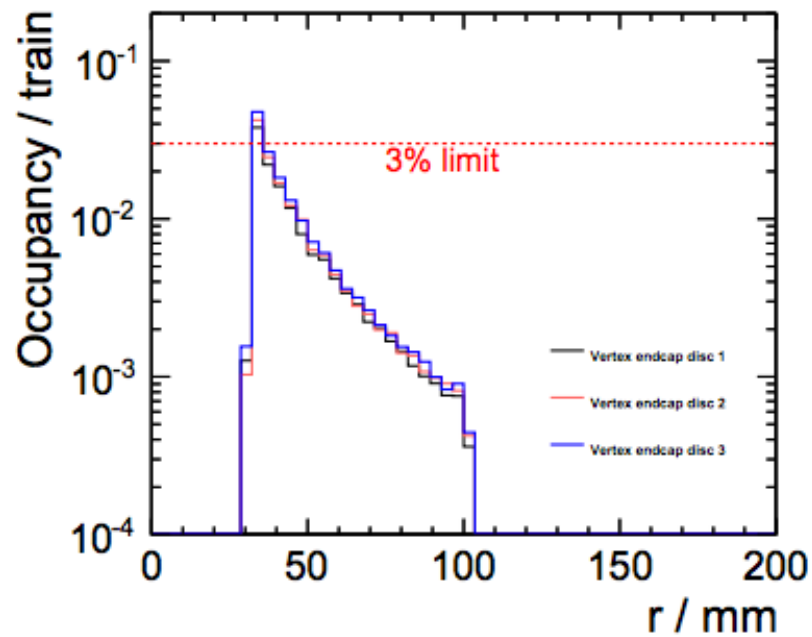
Vertex-detector cell sizes

- Vertex-detector readout granularity driven by:
  - Background occupancies → not more than a few percent per bunch train
    - Incoherent e^+e^- pairs and γγ→hadrons
    - For 25 µm pixel pitch: ~ 3-5% train occupancy in innermost layers (dominated by direct hits thanks to forward-region optimisation)
    - Safety factors of 5 (incoh.pairs) and 2 (γγ→hadrons) assumed, cluster size 5 (conservative!)
    - *Background levels pose rather hard constraint, not much room for improvement*
  - Single-point resolution → ~3 µm
    - Technology dependent
    - *Barely achievable* with 25 µm pixel pitch and 50 µm sensor thickness

Hit rates VTX barrel



Hit rates VTX FWD disks

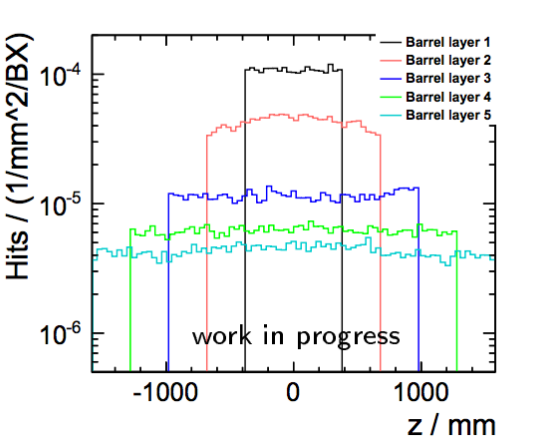


Outer tracker cell sizes

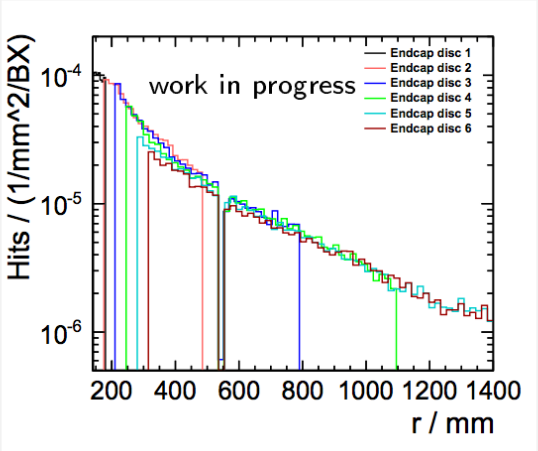
- Similar considerations as in vertex-detector region
- Single-point resolution goal in Rϕ:
  7 µm → ~50 µm width
- Background occupancies drive strip (pixel) length:
  ~3% occupancy → 1-10 mm length,
  depending on layer radius

Beam-induced background hits from γγ→hadr. and incoh. pairs

Barrel



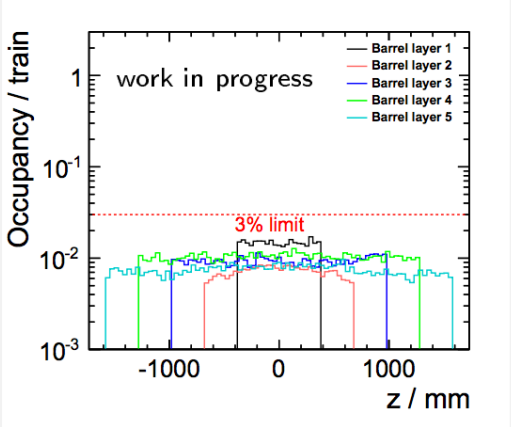
Endcap discs



Main tracker cell sizes

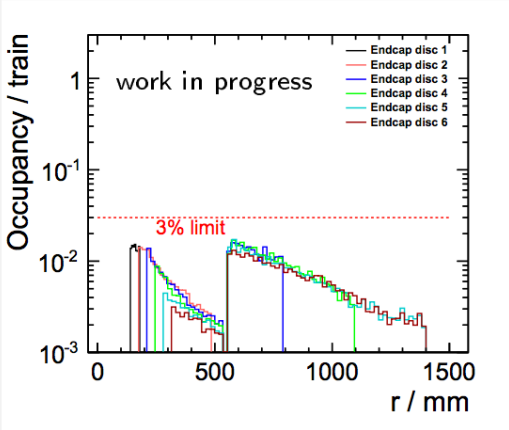
Barrel

Barrel layer	Strip length / mm
1 & 2	1
3	5
4 & 5	10



Endcap discs

- inner discs: 1 mm strips
- outer discs: 10 mm strips

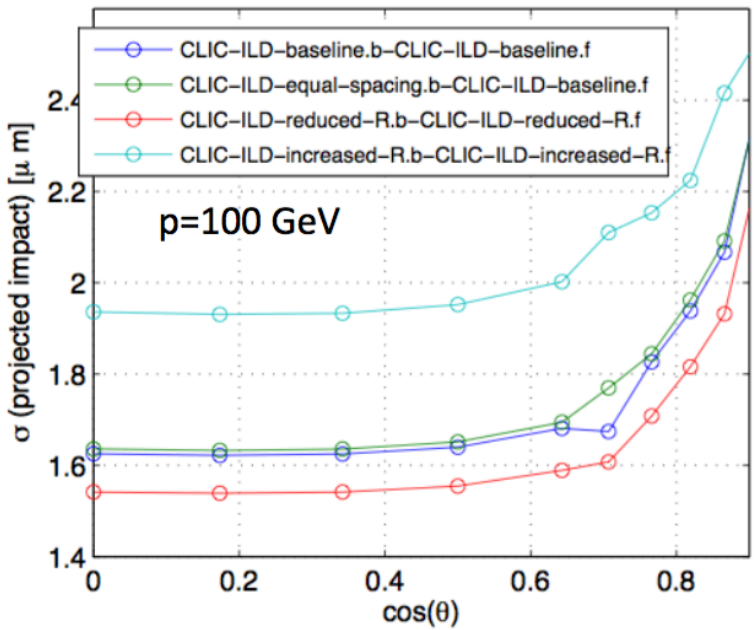


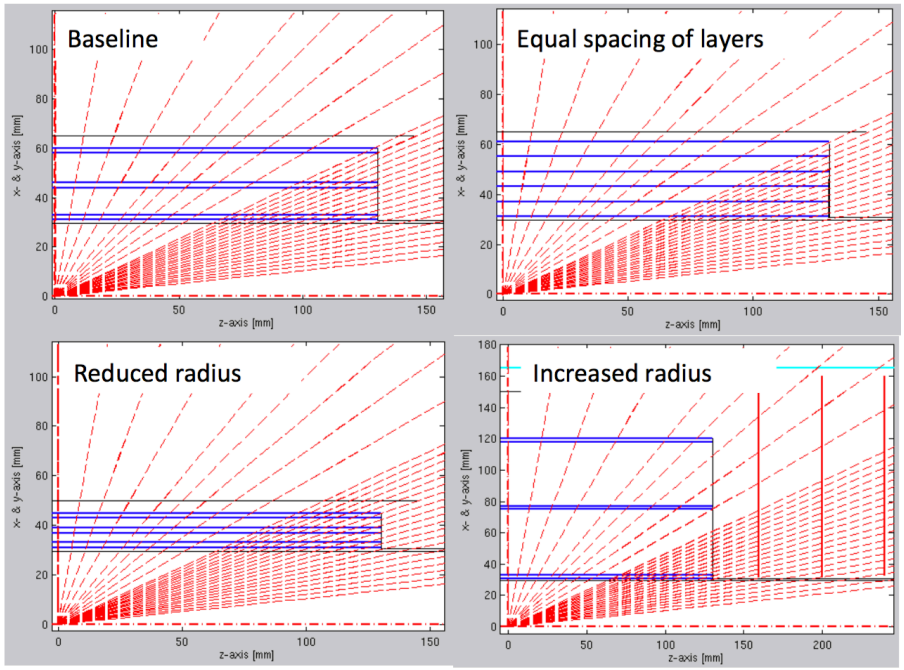
M. Munker, A. Nürnberg

Vertex-detector layout optimisation

- Optimisation studies performed so far:
  - Fast simulation (LiC toy) → impact parameter resolution as function of energy, angle
  - Full simulation with LCFI plus → flavour-tagging performance as function of energy, angle
  - Parametrised study for Hvv benchmark → impact of flavour-tagging on physics analysis
- Results in a nutshell:
  - Large impact on performance: distance of innermost layer to IP, material budget, resolution
  - Small impact on performance: arrangement of layers, short vs long barrel, spiral endcaps
  - Compact arrangement of layers is favorable for high-momentum particles
- Tracker was included in studies, but tracker geometry was not varied
- In particular: no studies of tracker performance in view of late decays (beyond vertex detector)

Imp.-param. resolution for different barrel geometries



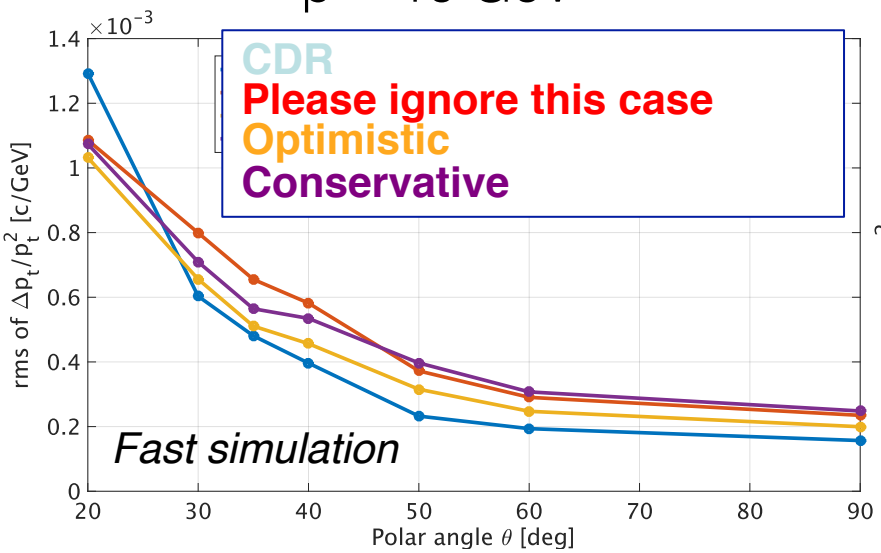


Tracker layout optimisation

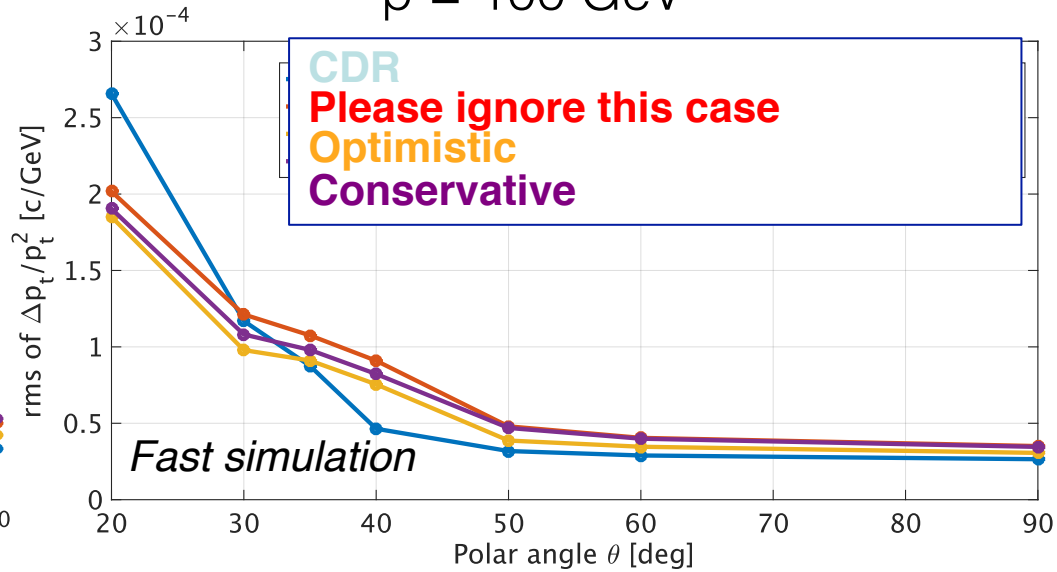
- CDR tracker layouts were taken over from ILD/SiD and (re-)optimised for:
  - uniform coverage
  - maximum forward acceptance (see above)
- Current CLIC tracker layout is SiD like (silicon only) and takes into account engineering and other constraints:
  - more material for supports and cabling: ~2%X0 per layer instead of 1%X0
  - more realistic gaps for services
  - longer forward region, in order to improve momentum resolution for forward tracks
  - larger barrel radius (1.45 m instead of 1.25 m), in order to improve momentum resolution
  - higher granularity in z and R coordinates (see above)
  - under study: extra forward disk, to improve track extrapolation in high-background environment (see below)?
  - to be studied: extra barrel layer, to improve impact-parameter resolution for late decays and mitigate effect of missing hits in overlap regions?

Material budget

p = 10 GeV



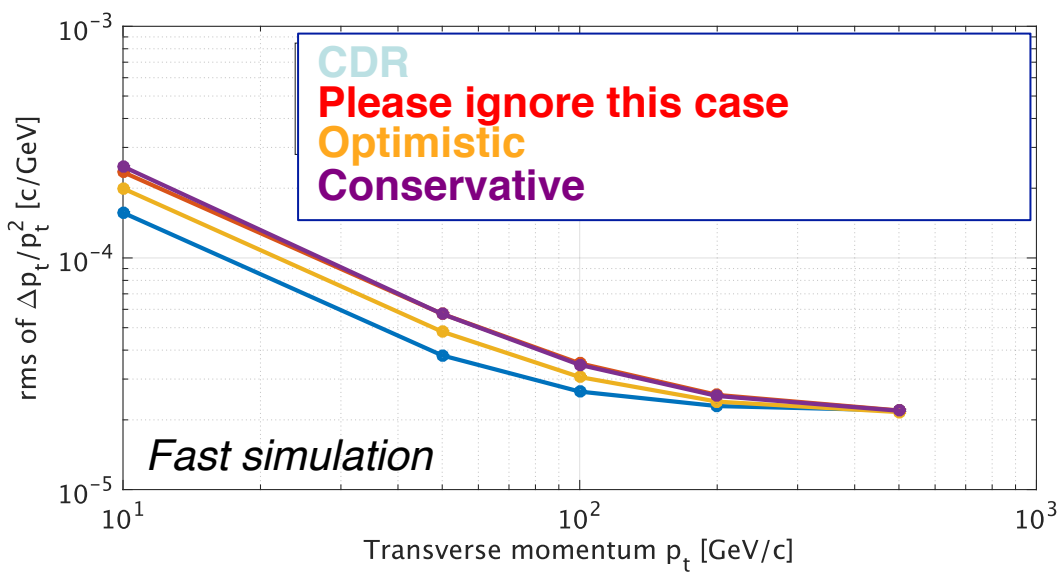
p = 100 GeV



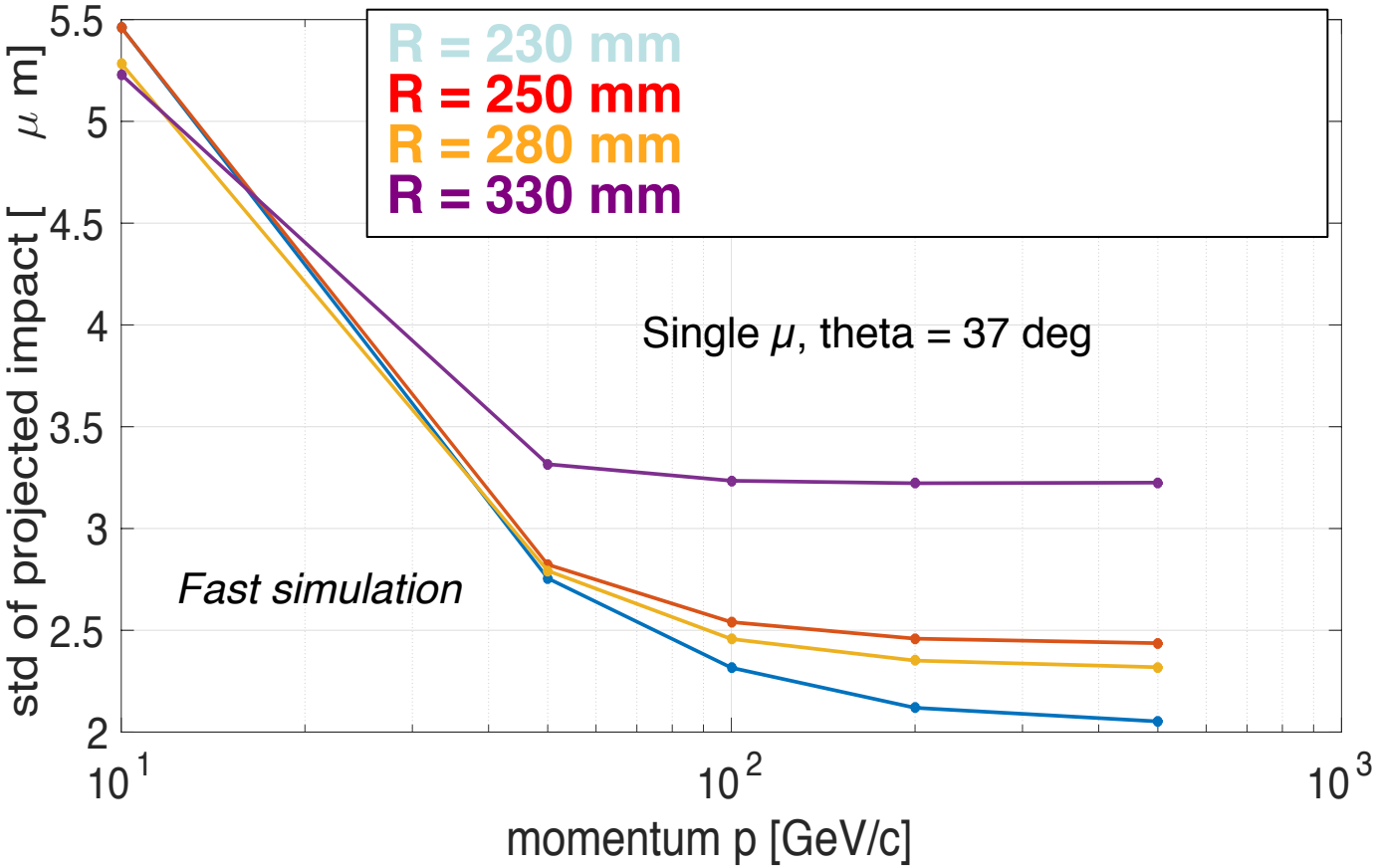
	B1	B2	B3	B4	B5
%X_0	1.57	2.15	2.06	2.13	2.13

- "Optimistic" case (similar to implementation in full simulation model) ***for 10 GeV muons ~25% worse than CDR***

θ = 90°

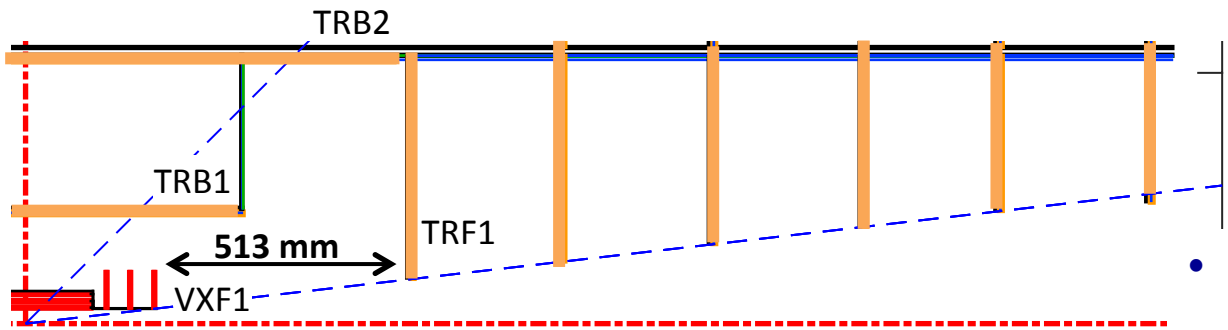


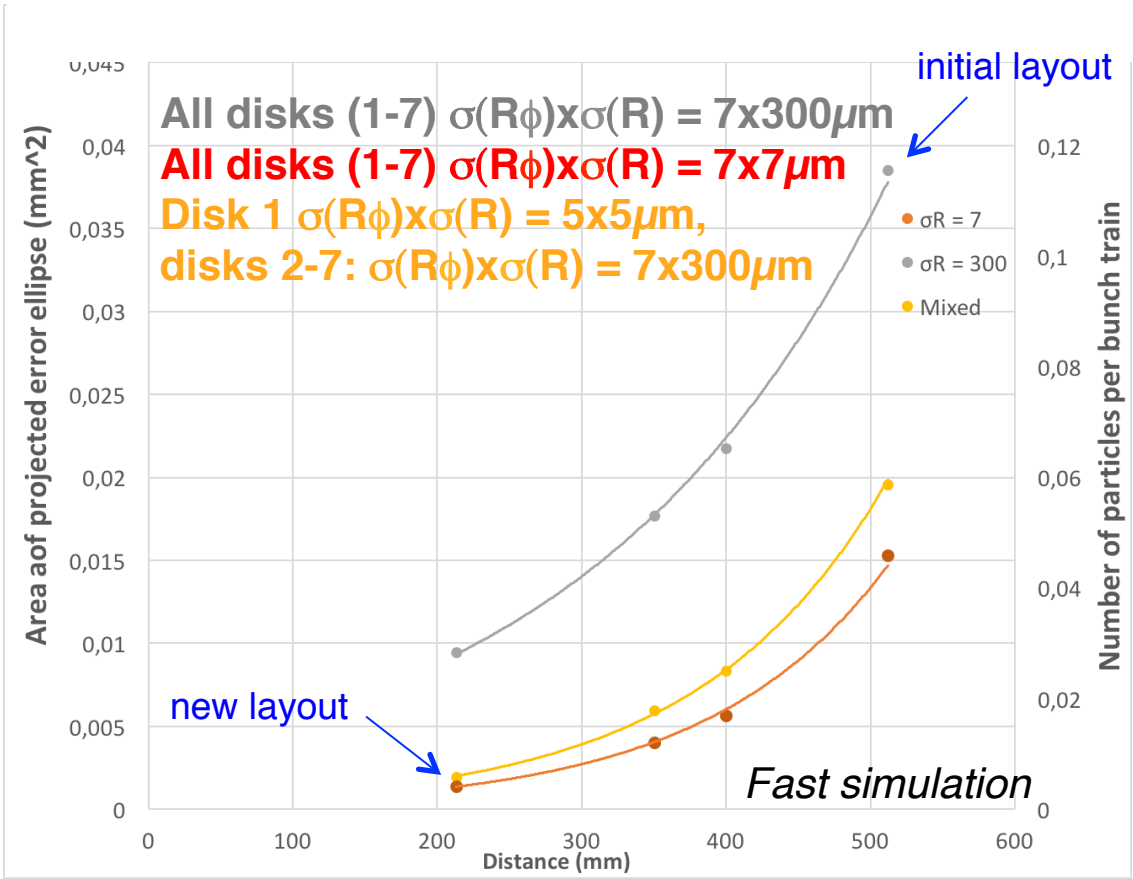
Radius of first layer



- Worsening of impact parameter resolution when moving the first tracker layer out

Extra endcap disk





- Driven by occupancy requirements → How many hits fall in the area defined by the track extrapolation errors?
- If we want less than few % bkg an ***extra layer*** is needed (rearrangement of the layers will cause large extrapolation for the other layers → it does not solve the problem even if bkg decreases with R)
- If we want less than 1% bkg the extra disk needs to be ***pixelated***
- No problem for mechanics

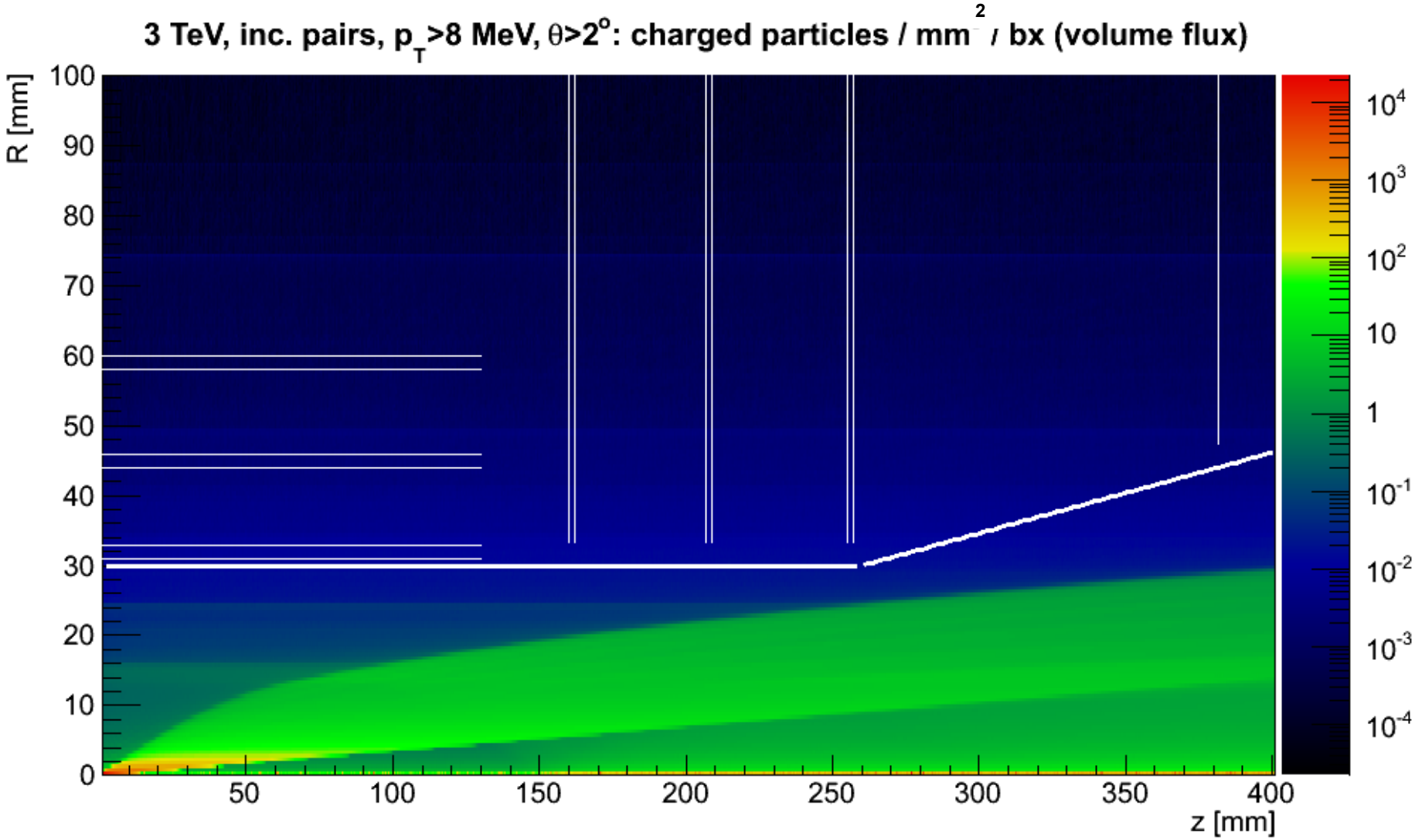
Proposal for future studies

Optimize tagging performance for late decay vertices from strongly boosted heavy flavored hadrons:

- Easy: Study fast-simulation impact-parameter performance for:
  - reduced number of vertex hits (including tracker standalone)
    [quick check this morning: 150 GeV muons d0 resolution worsens from 1.6 μm to 11 μm when removing hits from vertex detector. Is this still good enough?]
  - different tracker geometries and resolutions
  - increase vertex-detector radius vs. decreasing tracker inner layer
  - extra vertex layer vs. extra tracker layer
  - *note: extra tracker layer is anyway under consideration, because the cooling system favors a geometry w/o overlapping modules (see Andreas' talk), leading to inefficient regions between modules that could be compensated for with an extra layer*
- More difficult: Full-simulation flavor-tagging performance studies
  - Re-do previous studies with improved tracking: allow for missing hits in all vertex layers (alternatively: bypass pattern recognition based on Monte Carlo true information)
  - Same as above, with different geometries
  - Results should tell us what the required impact-parameter resolution for late decays is
- Rather long term: Physics benchmark studies
  - Guidance for fast-simulation studies: which kinematic region is most important? Trade-off between early and late decays? (see Philipp's talk, could partially be done on generator level?)
  - Impact of flavor-tagging performance on analysis results (needs full simulation)

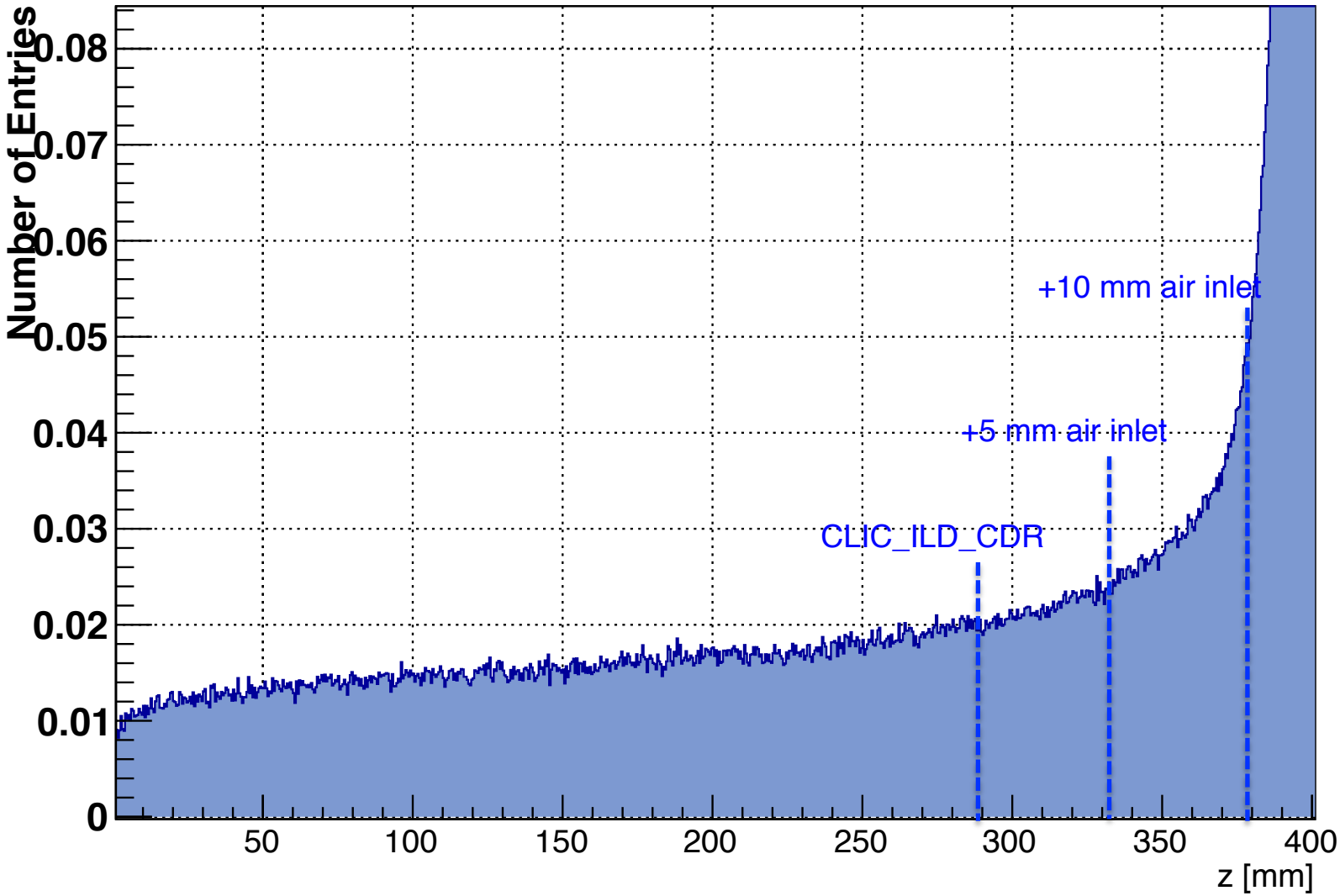
Additional material

Hit density in vertex region

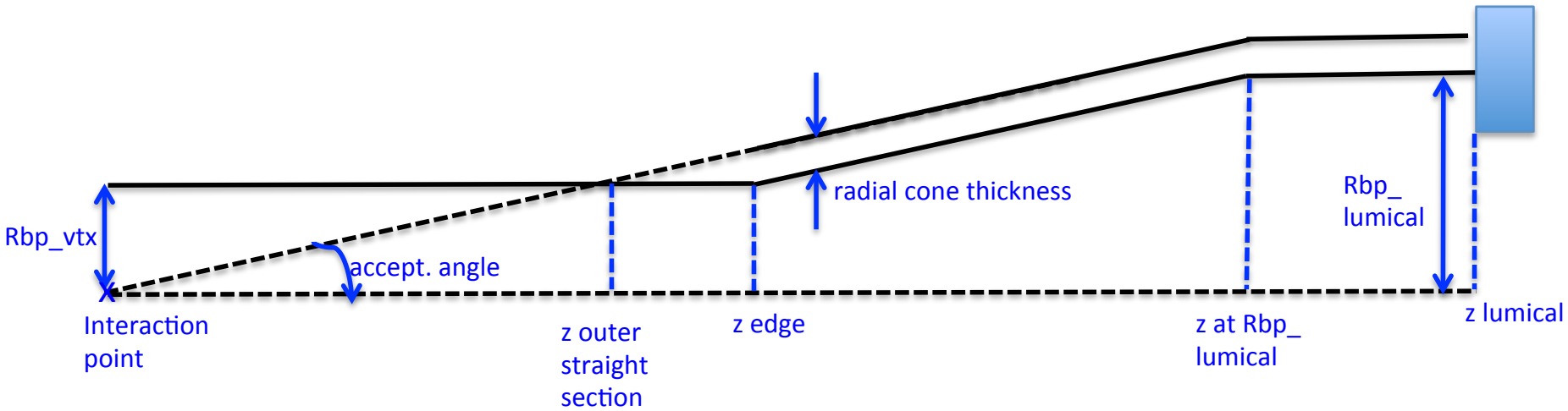


Hit density at R=29 mm

3 TeV, incoh. pairs: charged particles / mm^2 / bx (volume flux) at R=29 mm

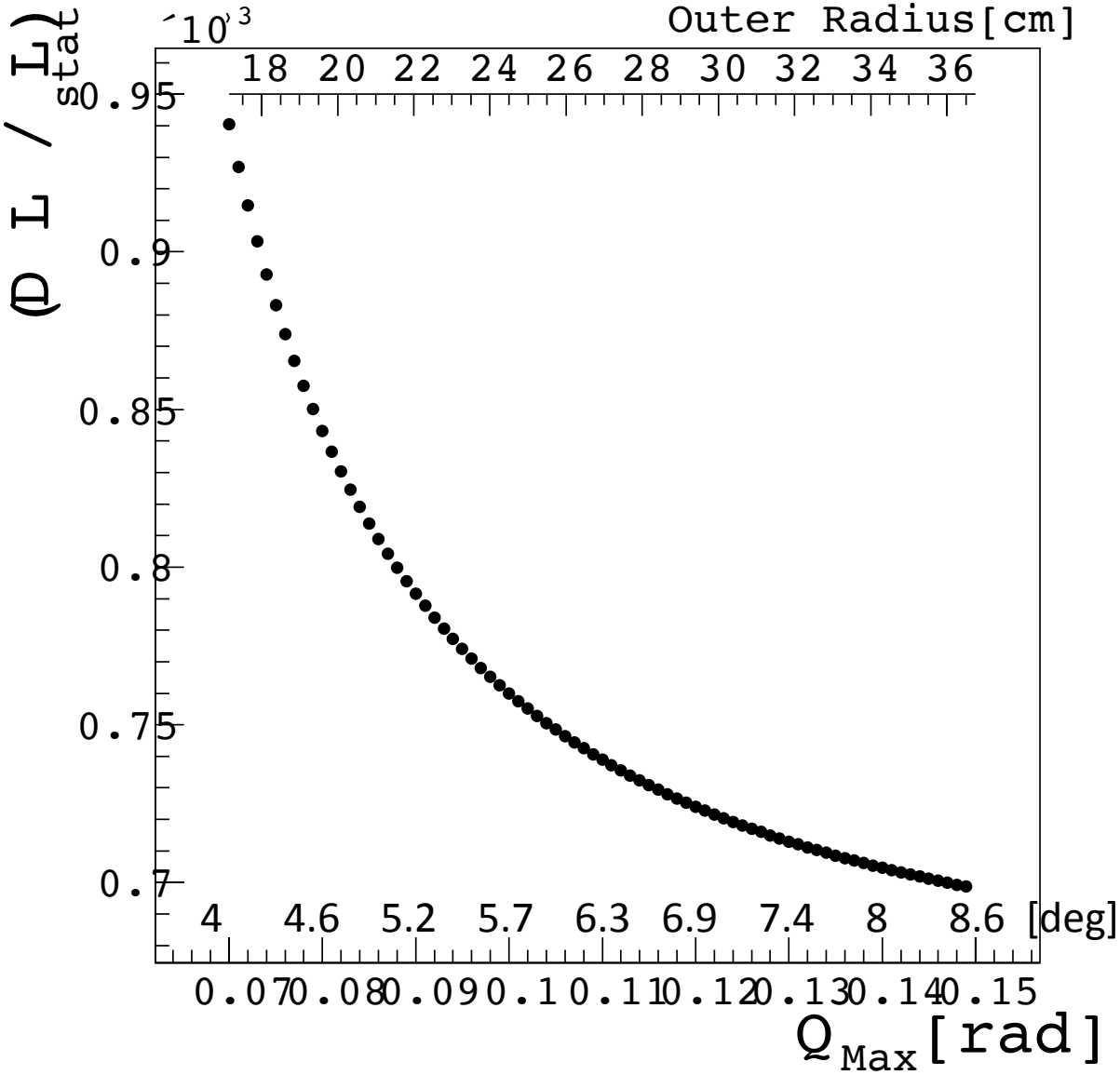


Forward acceptance

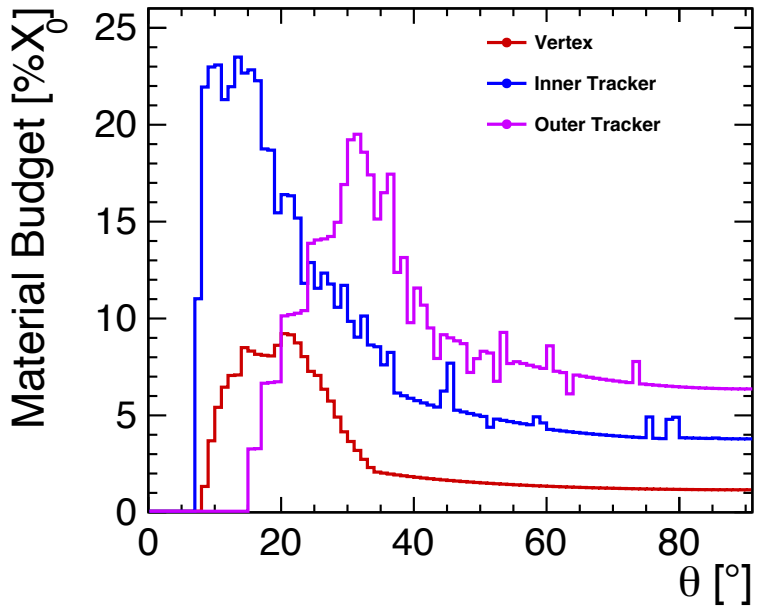


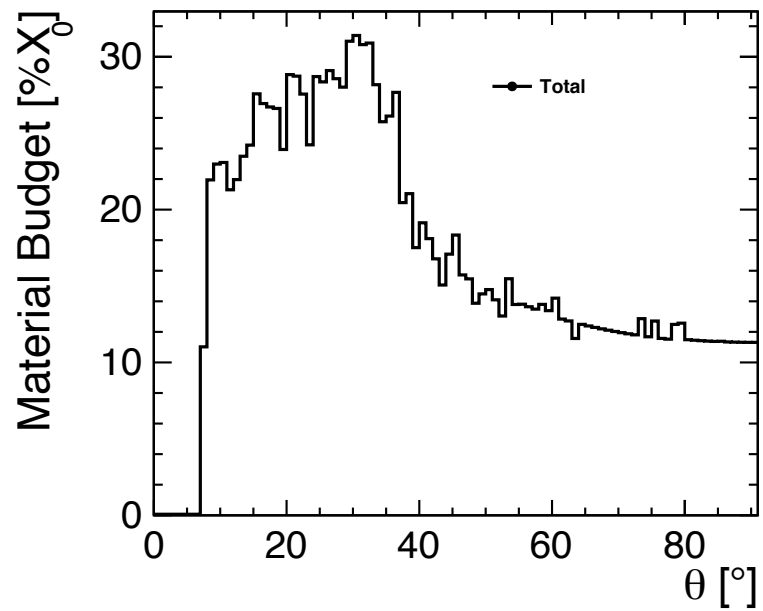
Geometry	CLIC_ILD_CDR	With 10 mm air inlet, same z edge	With 5 mm air inlet, same z edge	With 10 mm air inlet, same accept. angle	With 5 mm air inlet, same accept. angle
Rbp_vtx [mm]	29	29	29	29	29
Rbp_lumical [mm]	240	240	240	240	240
z_lumical [mm]	2450	2450	2450	2450	2450
Accept.angle [rad]	0.1137	0.1477	0.1308	0.1137	0.1137
Accept angle [deg]	**6.51**	**8.46**	**7.49**	**6.51**	**6.51**
Radial cone thickness [mm]	4	14	9	14	9
Real cone thickness	3.974	13.848	8.923	13.910	8.942
z outer straight section [mm]	254.0	194.9	220.4	254.0	254.0
z edge	**289.0**	**289.0**	**288.9**	**376.6**	**332.8**
z at Rbp_lumical [mm]	2101.7	1613.1	1824.4	2101.7	2101.7

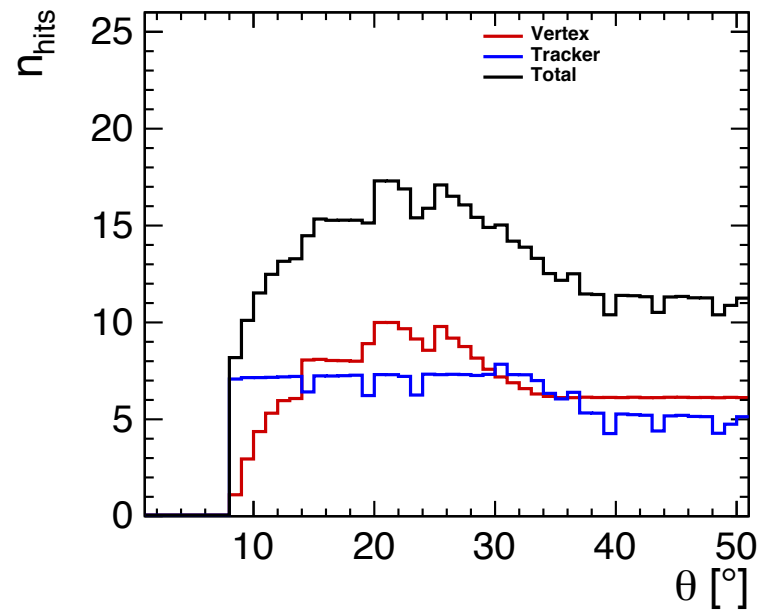
LumiCal acceptance



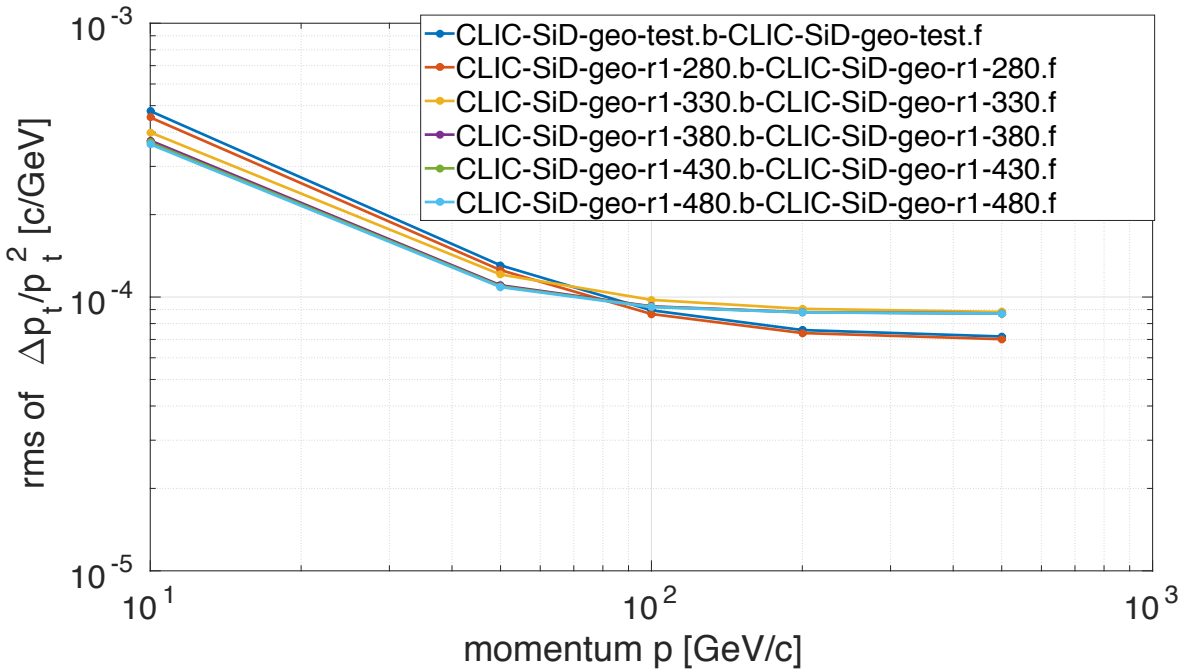
André Sailer


Material Budget [%X0]
Vertex
Inner Tracker
Outer Tracker
θ [°]


Material Budget [%X0]
Total
θ [°]

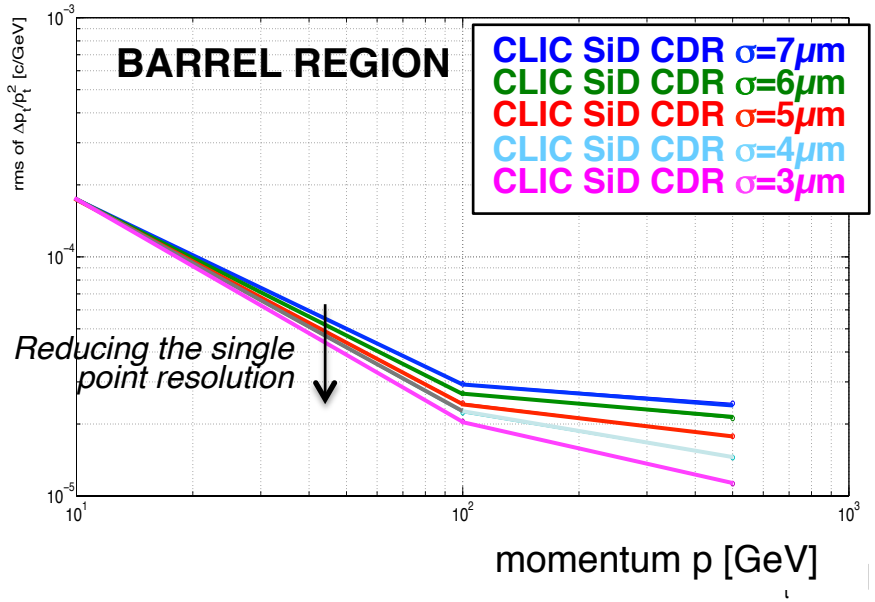

nhits
Vertex
Tracker
Total
θ [°]

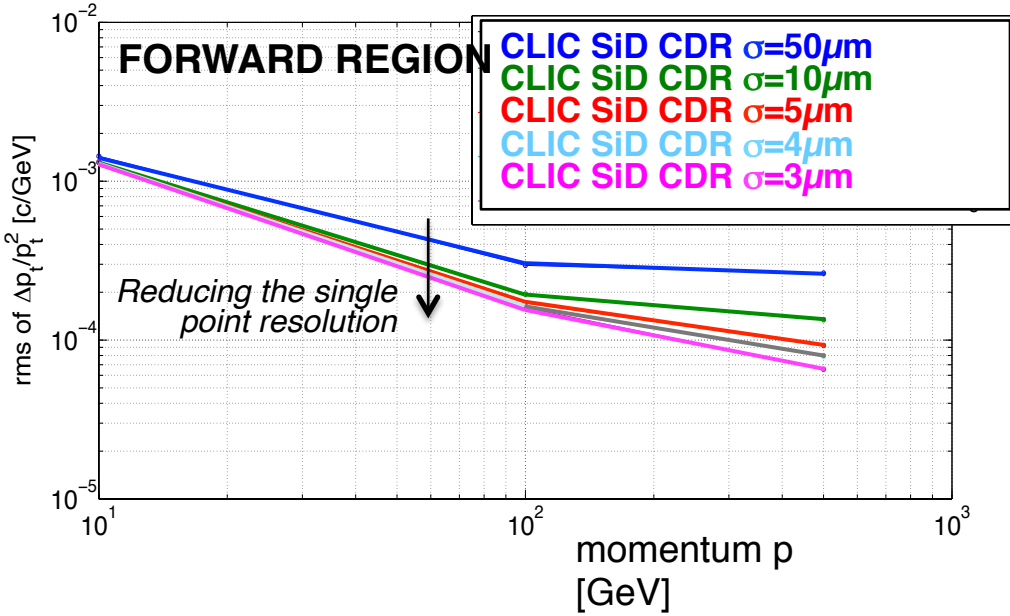
Results vs momentum



- *For low pT: multiple scattering is important → larger radius preferred for lower m.b.*
- *For high pT: track more straight → it is important to have a layer closer to the VXD*

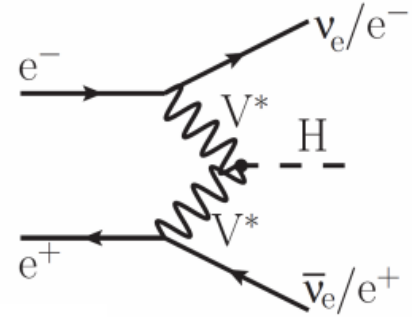
Single point resolution

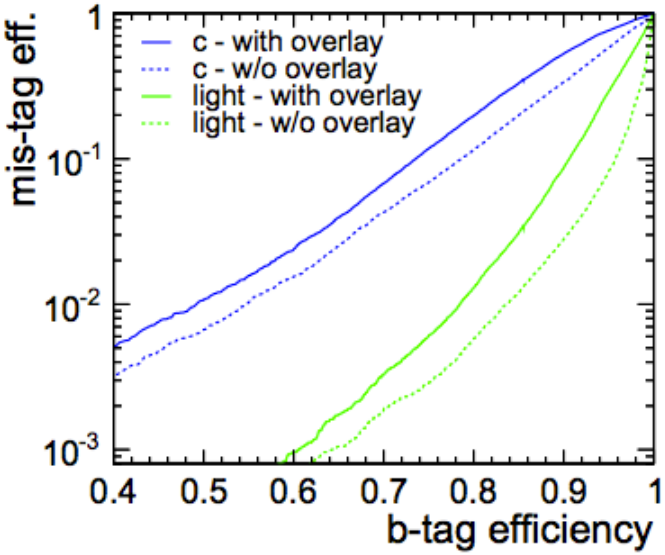


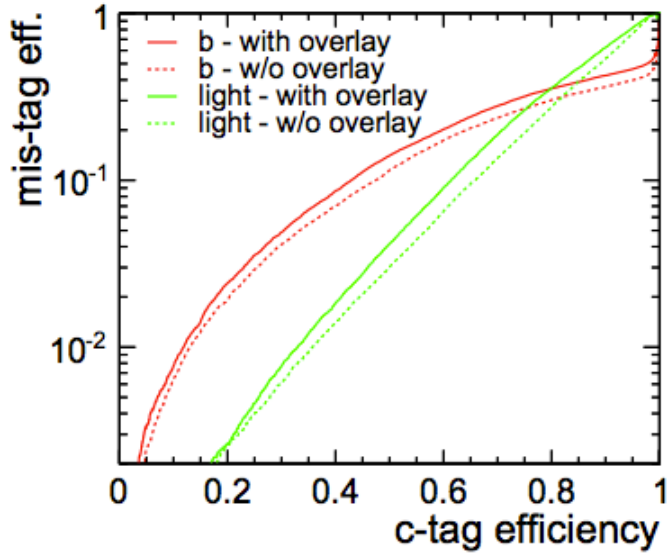


Flavor tagging: impact on physics performance

- $e^+e^- \rightarrow H\nu\nu$: dominating Higgs production process at $\sqrt{s}$=3 TeV
- σ × BR measurement for the decays to bb and cc
- flavor tagging crucial for achievable precision







$\sqrt{s}$=3 TeV
L_{int}=2 ab^{-1}

$p_{T,jet}$~70 GeV
E_{jet}~130 GeV

channel	stat. unc. on σxBR	change for +/-20% fake r.
H➔bb	0.23%	0.24% / 0.21%
H➔cc	3.1%	3.6% / 2.6%

- consider ±20% change in fake rates
- sizeable effect, in particular for H→cc: 30% more integ. luminosity required for same precision when increasing fake rate by 20% (>1 year of additional running!)

LCD-Note-2011-036, CLICdp Note-2014-002