Layout optimisation for the vertex and forward-tracking region in the CLIC_ILD and CLIC_SiD detector concepts

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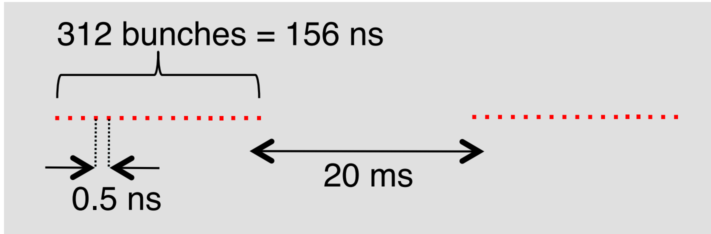
Outline

- CLIC environment for vertexing and forward tracking
- Optimisation strategy and framework
- CLIC_ILD and CLIC_SiD tracking detector models
- Design optimization and validation studies:
  - single-point resolution
  - Material budget
  - Layer placement
  - Forward tracking
- Conclusions/Outlook

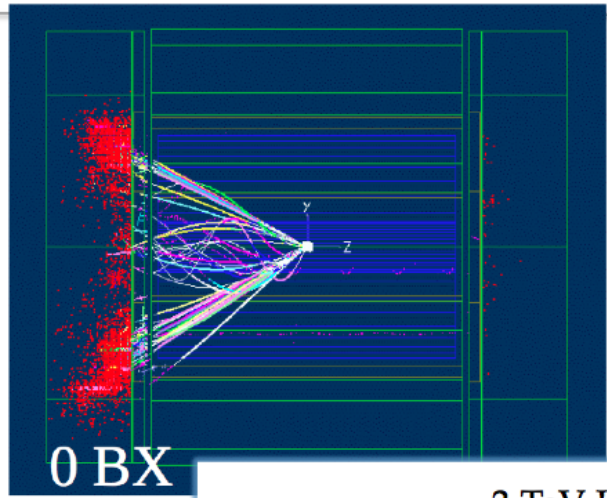
Vertexing and forward tracking at CLIC

- e^+e^- collisions at up to sqrt(s)=3 TeV, L_{inst}~10^{34} /$cm^{-2}s^{-1}$
- 312 bunch crossings within 156 ns, bunch-train repetition rate of 50 Hz



- Aiming for similar precision as for ILC detectors:
  - $\sigma_{1/pt} \sim 2\times10^{-5}\text{GeV}^{-1} \oplus 10^{-3}/(p_T \sin\theta)$
  - $\sigma_{r\phi} \sim 5\ \mu m \oplus 15\ \mu m\ \text{GeV} / p_T$

  →**little material** and **good resolution**, to allow for efficient **heavy-flavor tagging**

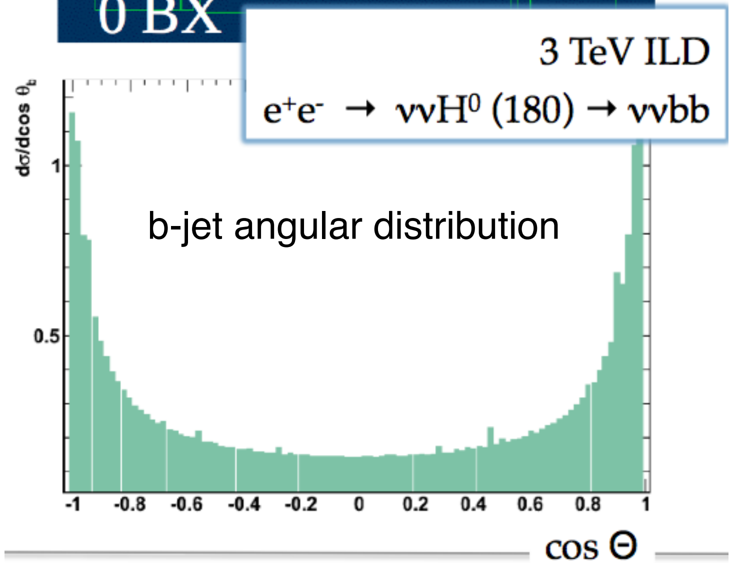


- High rates of machine-induced backgrounds:
  - Up to ~0.04 hits $mm^{-2}\ ns^{-1}$ in innermost layers from incoherent pairs

  → **high granularity** and **time stamping**, to allow for efficient **pattern recognition**

- Many physics processes peaked in forw. region

  →emphasis on **forward tracking**



Optimisation strategy and framework

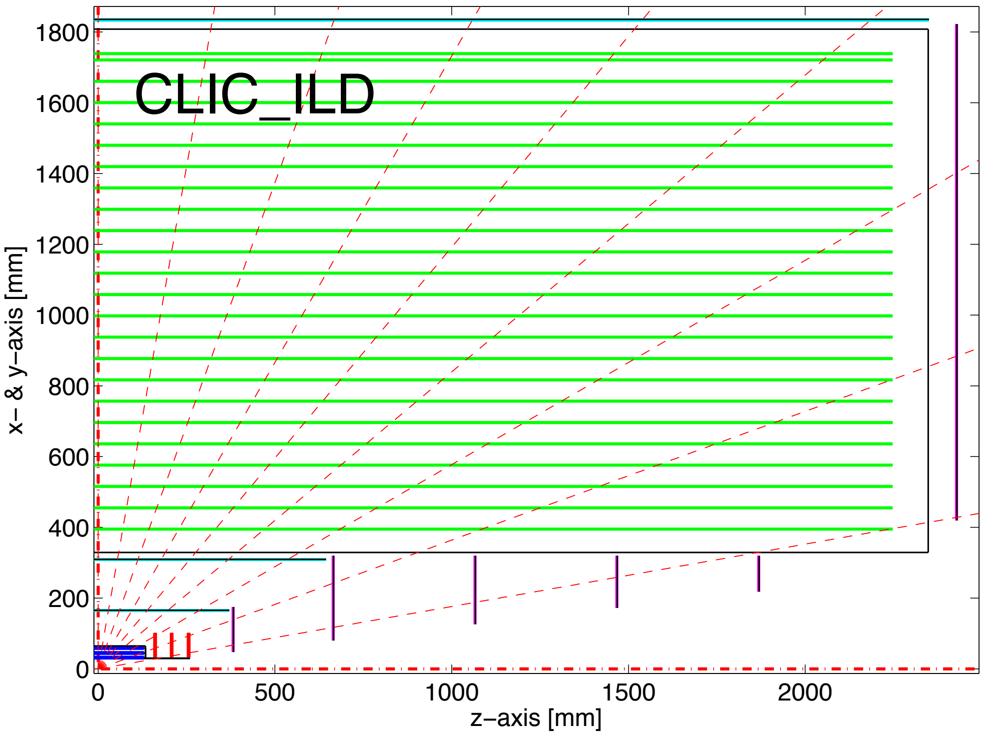
- Started from validated ILC tracking-detector designs: **ILD** and **SiD**
- Adaptations for CLIC (background-) conditions: forward region, distances to IP
- Where applicable: **complementary choices**, to study influence on performance
- Fully implemented in Geant-4 simulation frameworks **Mokka** (ILD) and **SLIC** (SiD)

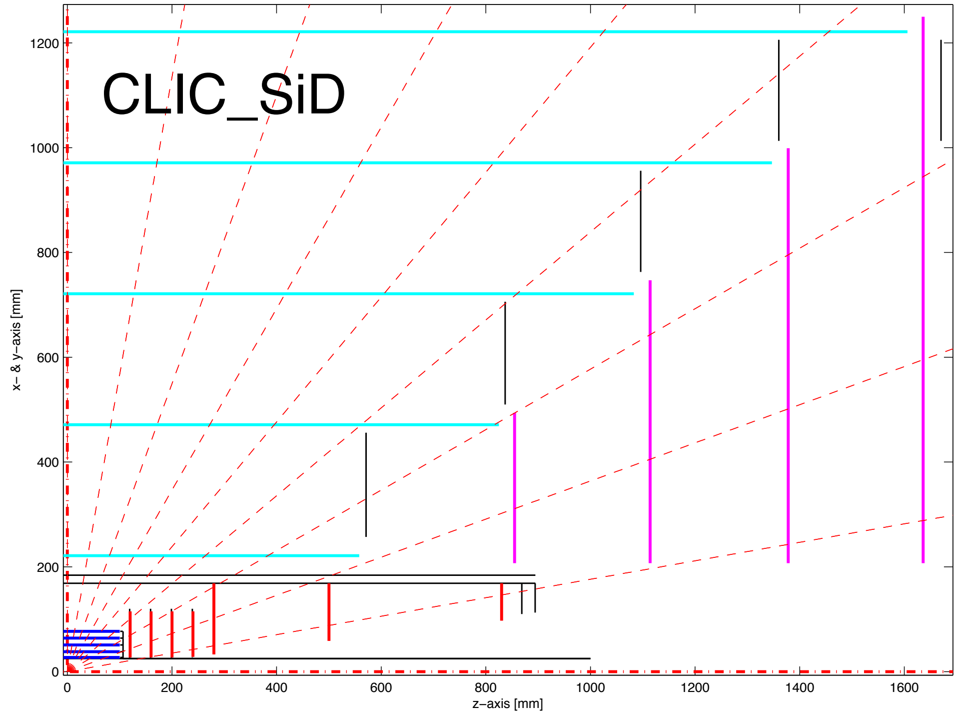
- Further **optimization** and **validation** of the layouts using fast simulations:
    - **LiC toy**:
        - MC simulation of hits in silicon cylinders and disks
        - Kalman-filter for outside-in track reconstruction
        - Validated with ILC full-simulation studies
        - Used for all layout and resolution studies
    - **CMS Kalman Filter**:
        - Parameterized description of detector elements and resolutions
        - validated with ILC and LHC full-simulation studies
        - Used for forward-tracking optimization

- In this talk we show **preliminary results** of these optimizations and validations

- Resulting designs **CLIC_ILD_CDR** and **CLIC_SiD_CDR** will be used for large-scale full-simulation MC studies towards a Conceptual Design Report (**CDR**), to be submitted in 2011
    - →Test layouts in the presence of machine-induced backgrounds
    - →More realistic validation of reconstruction strategies, resolutions, efficiencies, …

Outer tracking

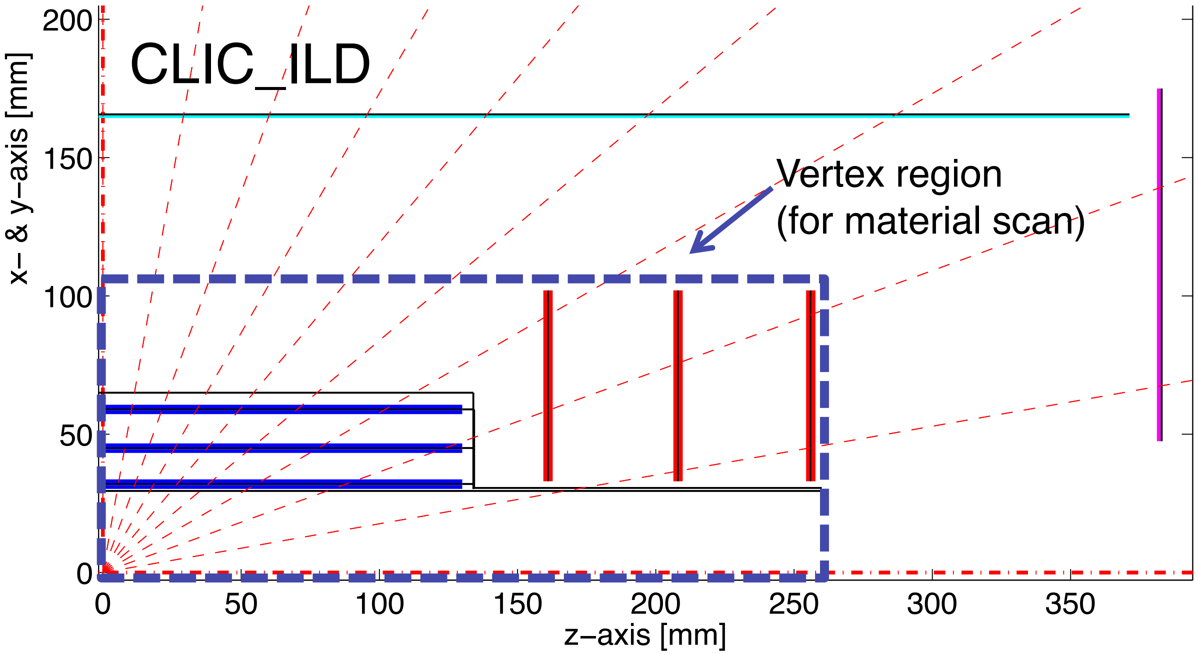




- B=4 T
- Time projection chamber (TPC):
  - 224 layers, $\sigma_{R\phi}$~100 µm per layer
- Outer silicon-strip envelope:
  - SET: 2 stereo cylinder layers, $\sigma_{R\phi}$=7 µm; σ_z=50 µm
  - ETD: triple-layer disk, $\sigma_{R\phi}$~σ_R~7 µm
- Inner silicon-strip envelope:
  - SIT: 2 stereo cylinder layers, $\sigma_{R\phi}$=7 µm; σ_z=50 µm
- Forward silicon-strip tracking:
  - FTD: 5 stereo disk layers, $\sigma_{R\phi}$=7 µm; σ_z=50 µm

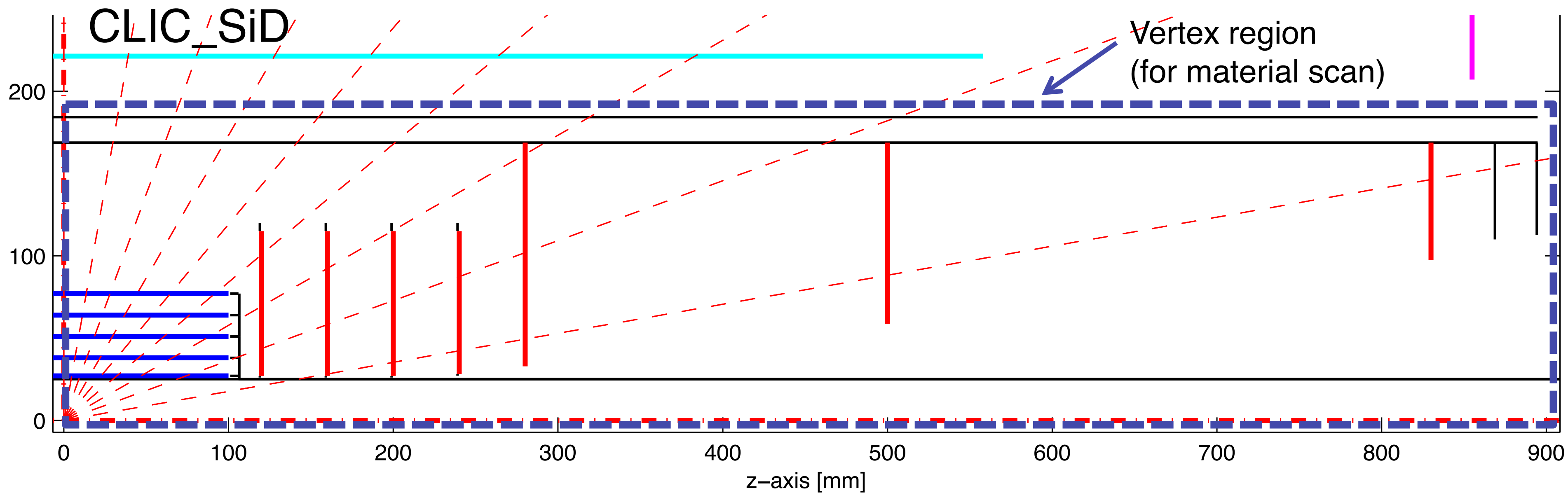
- B=5 T
- Outer Tracker Barrel (TRB):
  - 5 single cylinder layers, $\sigma_{R\phi}$=14 µm
- Forward Tracker (TRF):
  - 4 single disk layers, $\sigma_{R\phi}$=14 µm
- Design of vertex region allows for fast insertion and removal

Zoom into vertex region

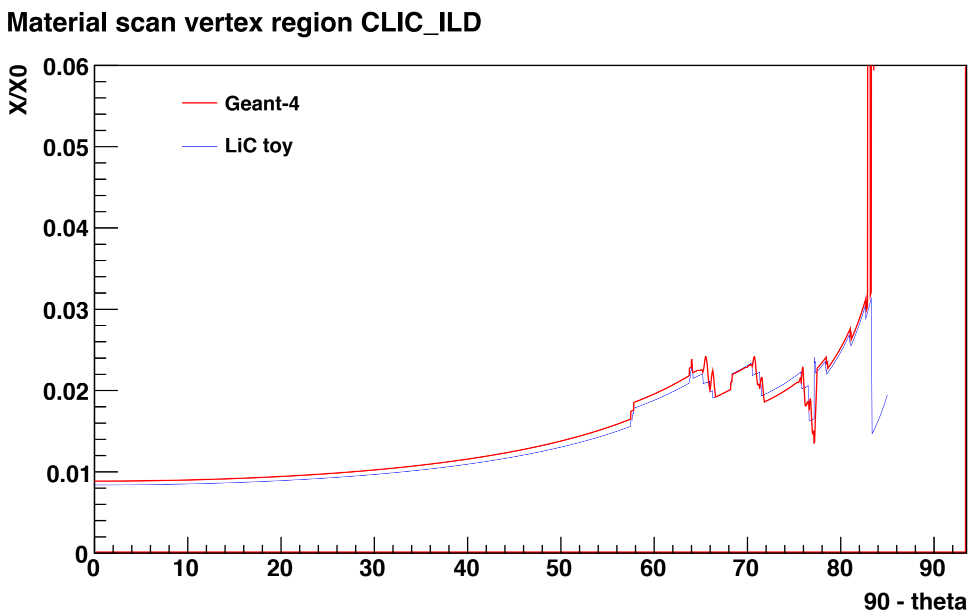


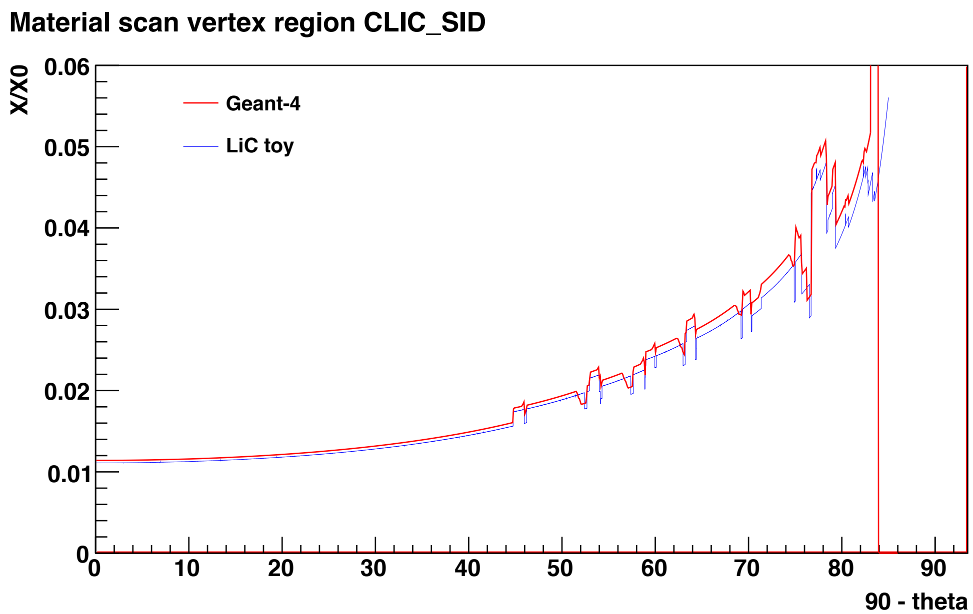
CLIC_ILD
0.6 mm Be beampipe at R=29.4 mm
3 double layers of pixel cylinders
3 double layers of pixel disks
20 µm pixels, analog readout, σ=2.8 µm
X=0.18% X0 / double layer
(2 x 50 µm Si + 134 µm Carbon Support)

CLIC_SiD
0.5 mm Be beampipe at R=25 mm
5 single layers of barrel pixel cylinders
7 single layers of forward pixel disks
20 µm pixels, digital readout, σ=5.8 µm
X=0.12% X0 / single layer
(50 µm Si + 130 µm Carbon Support)



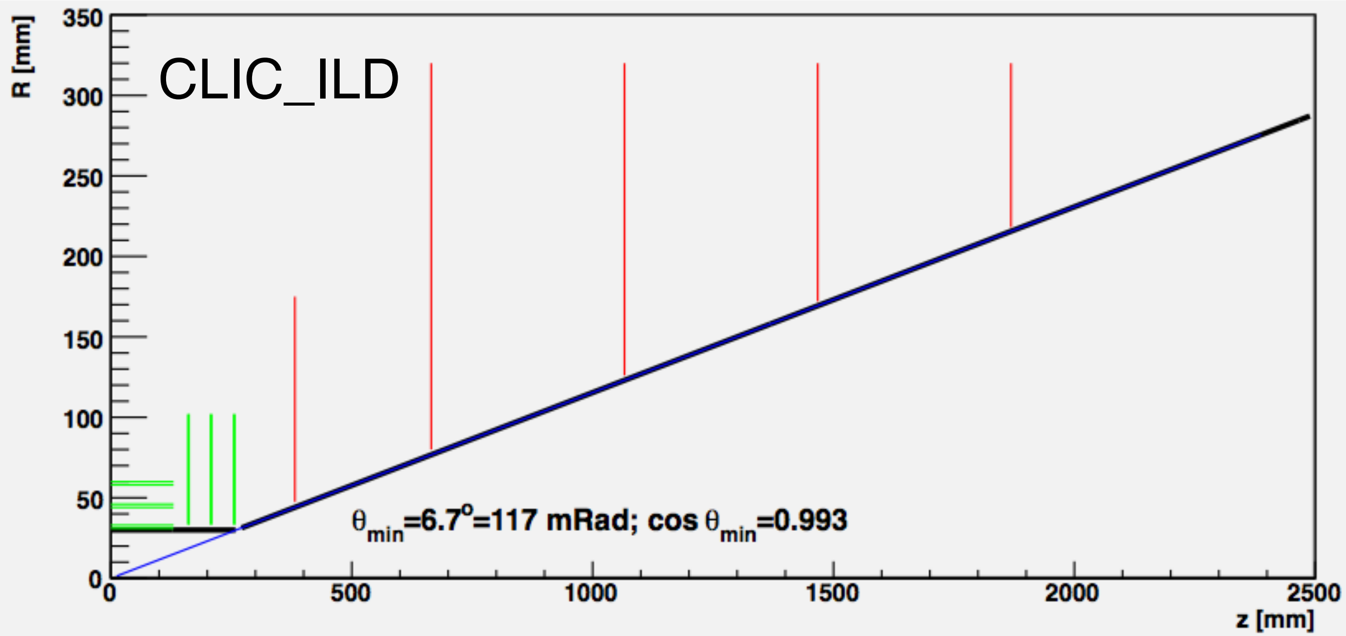
Material budget in vertex region

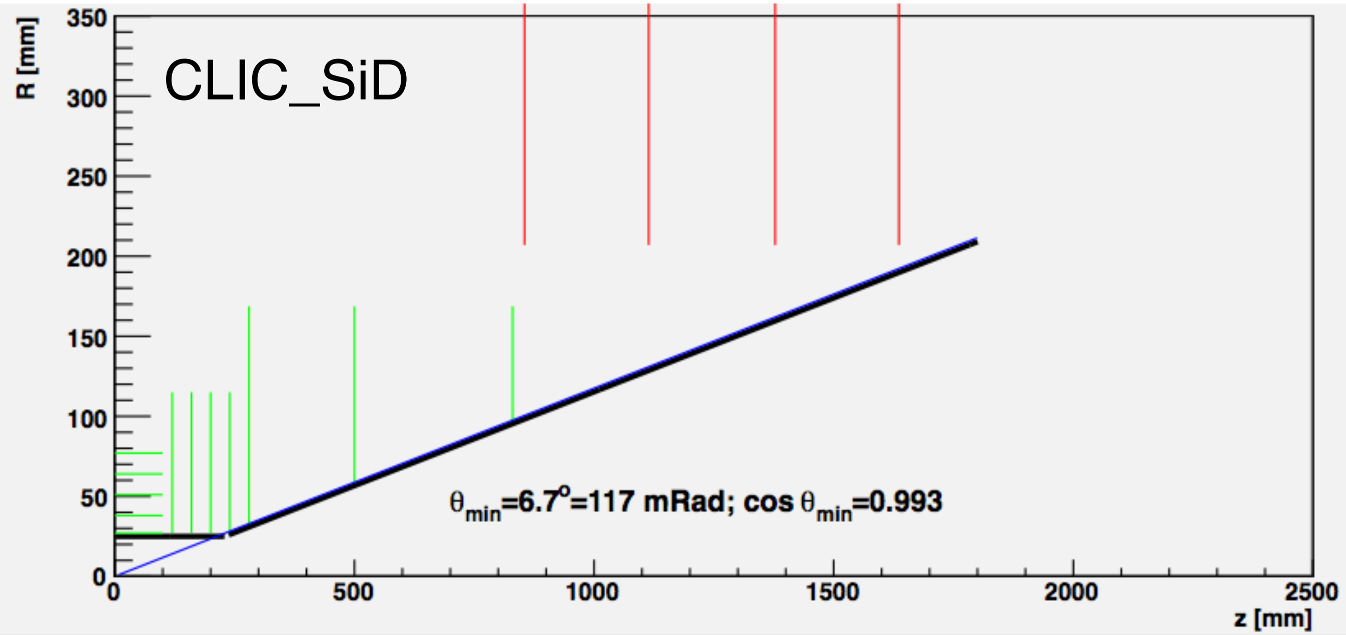




- Good agreement between material descriptions in fast and full simulation
- Remaining differences understood to be caused by the effect of more detailed modeling of detector and readout elements in the full simulations (e.g. planar modules as opposed to ideal cylinders and disks)
- 30-70% more material in the vertex region of CLIC_SiD:
  - ~doubled support due to the single layers
  - One more pixel disk
  - More material in outer support shell that had been designed with push-pull option in mind (included in these plots, though it does not affect the performance of the VTX detector itself!)

Beam pipe and forward region





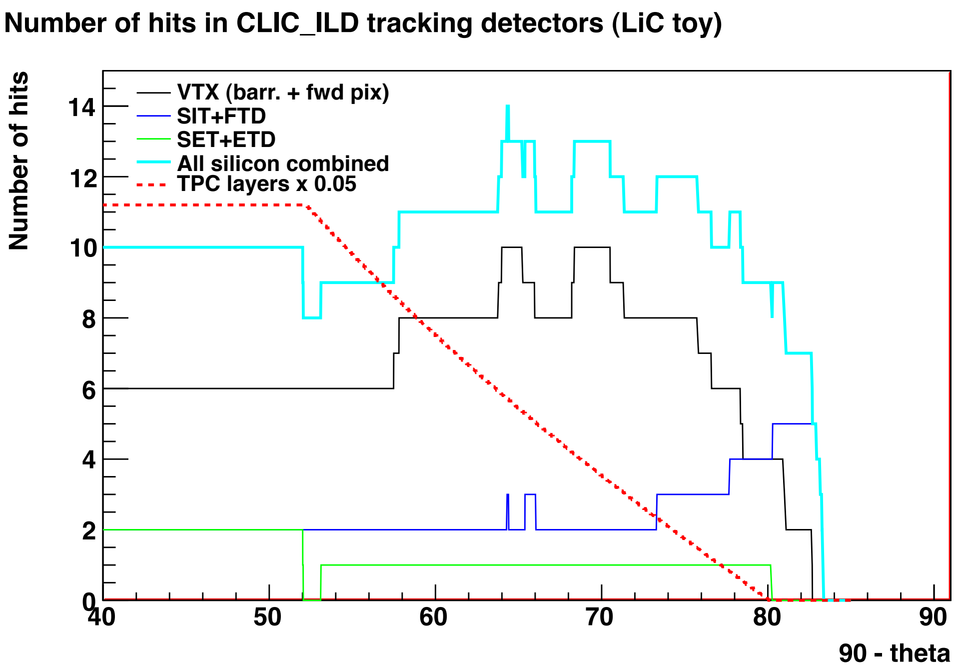
Similarly optimized forward design for both concepts:

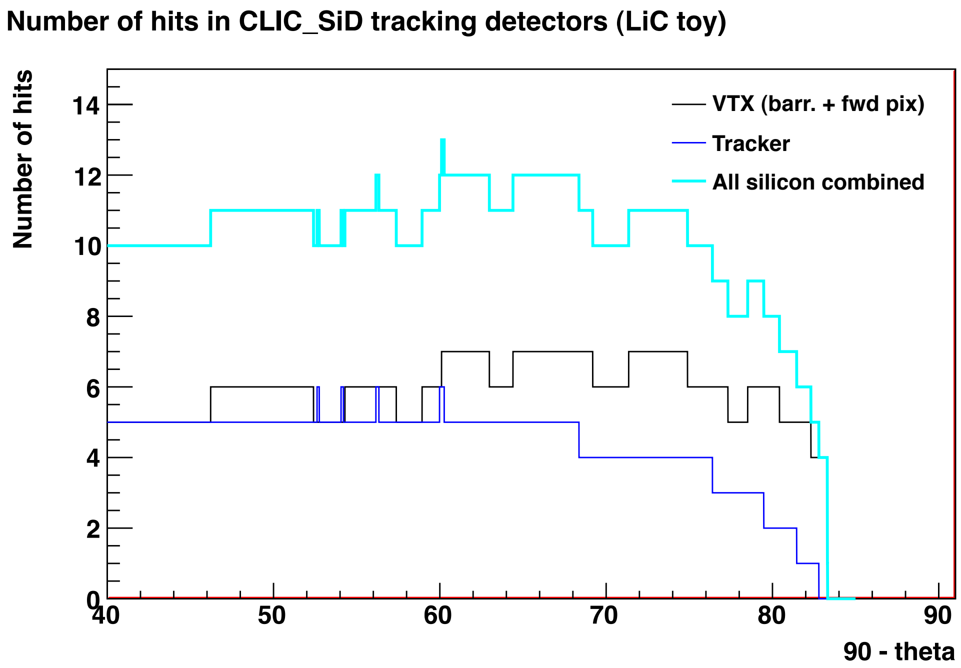
- Closest possible distance to IP given the constraints from backgrounds and magnetic fields
- Moved conical part out in z as far as possible, given the constraints from
  - direct pair-background hits
  - Forward-calorimeter acceptance

→cf. Christian Grefe's and André Sailer's talks in Performance + MDI sessions for more details

- Final forward acceptance is very similar for both concepts

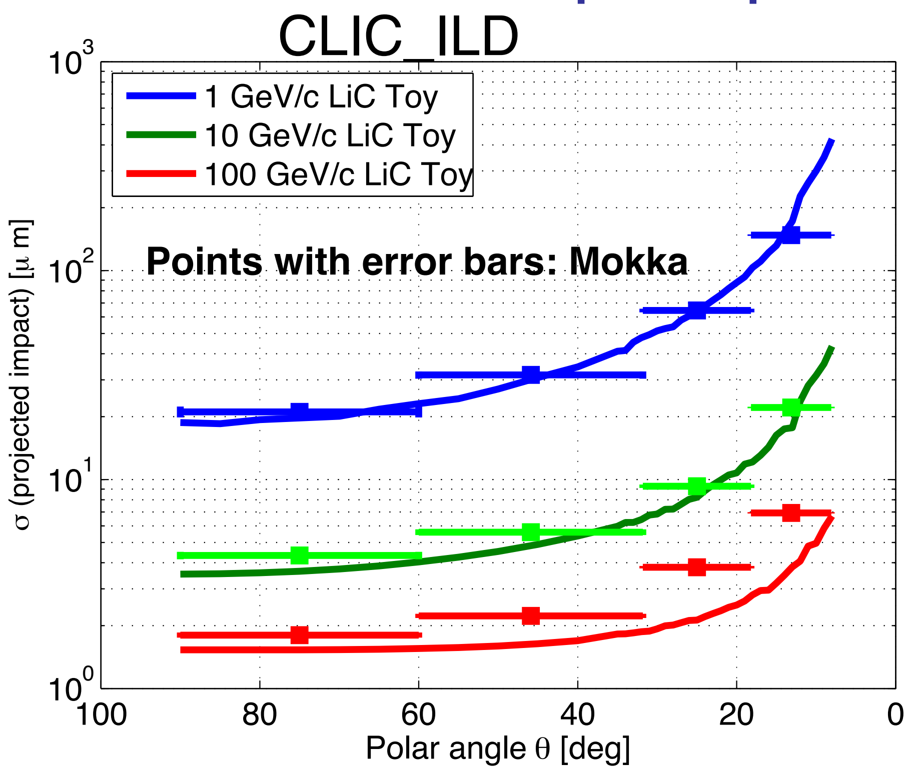
Tracking acceptance

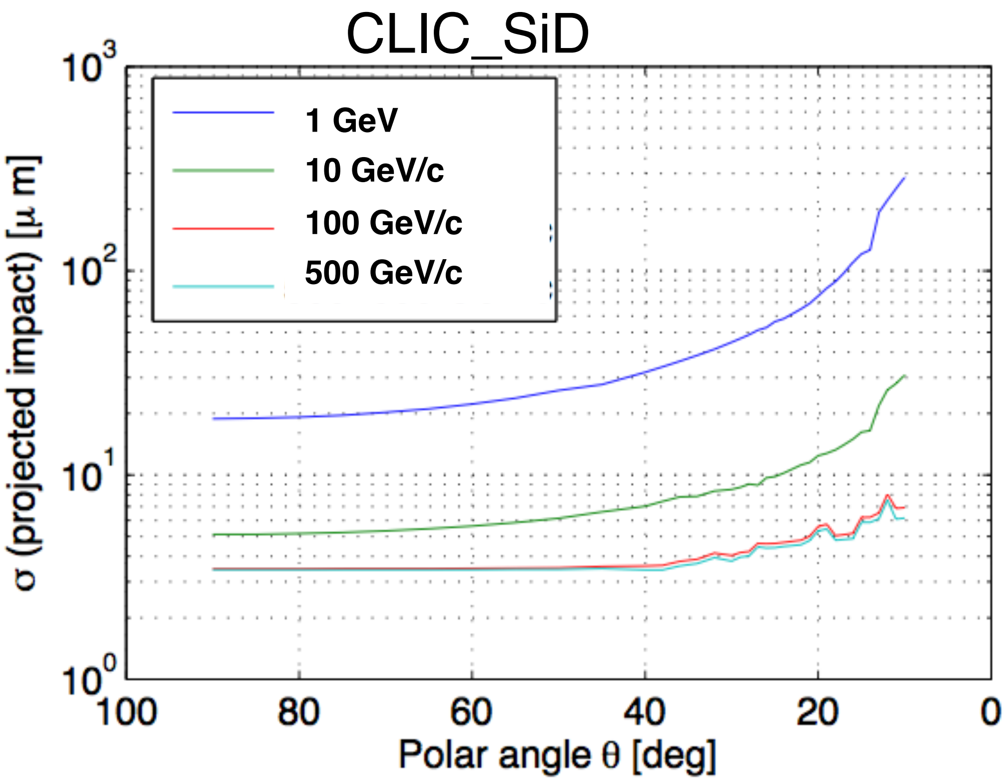




- For both concepts:
  - Similar overall acceptance
  - Similar number of silicon planes
  - Rather smooth transitions between regions, avoiding acceptance holes
- CLIC_ILD has a TPC in addition

Impact-parameter resolution





CLIC_ILD:

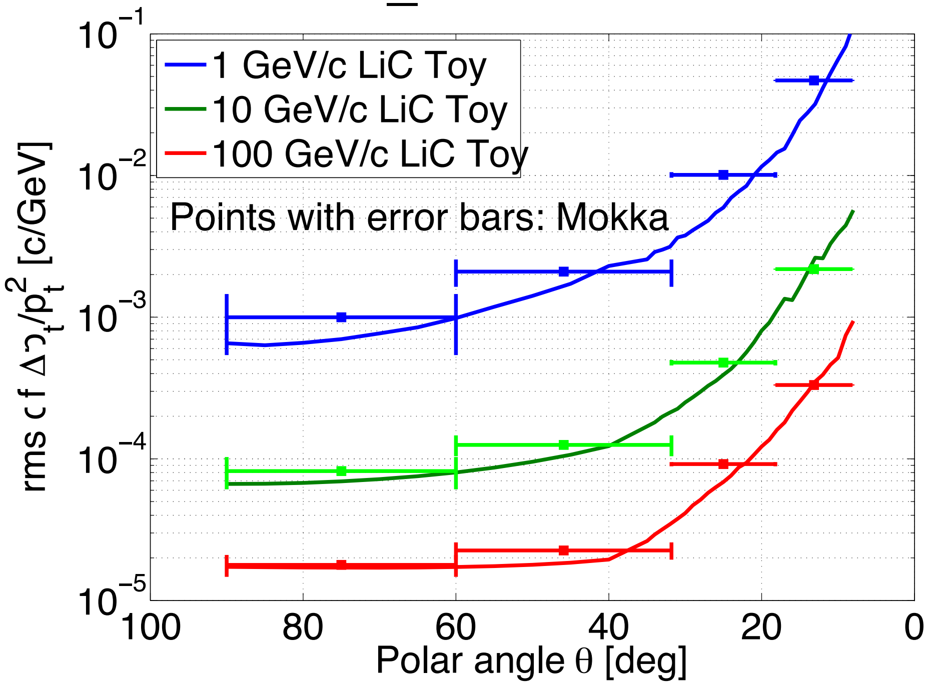
- ‘a’~1.8 µm, ‘b’~20 µm / GeV (in barrel)
- Good agreement between full and fast simulation
- Except for large momenta in the forward region, to be investigated further

CLIC_SiD:

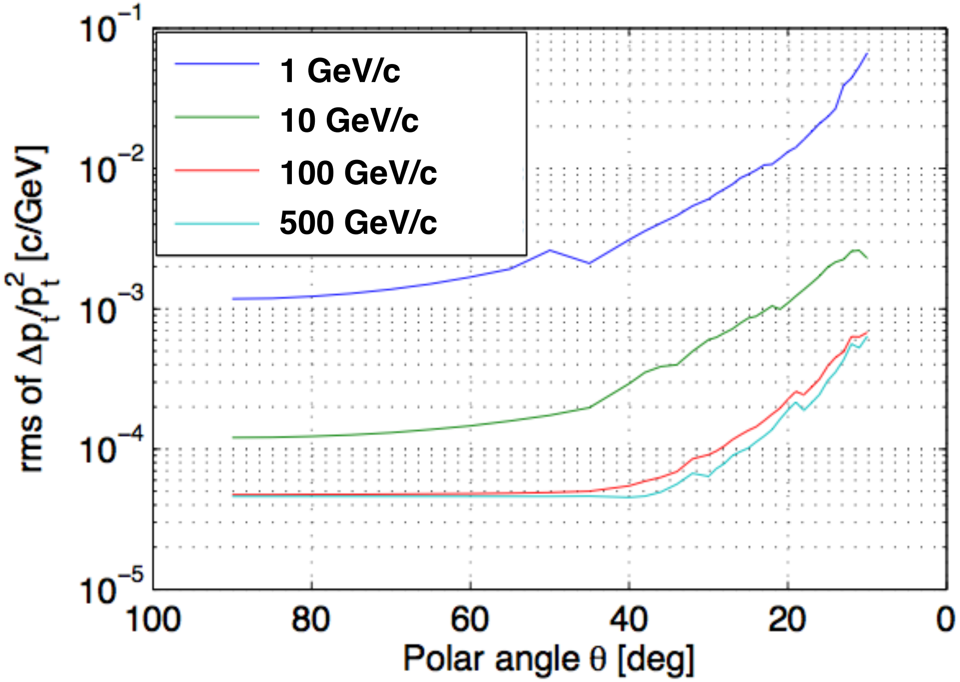
- ‘a’~3.4 µm, ‘b’~19 µm / GeV (in barrel)
- Larger ‘a’ parameter w.r.t. CLIC_ILD_CDR from 2 x larger single-point resolution (digital as opposed to analog readout)

$1/p_T$ resolution

CLIC_ILD



CLIC_SiD



- For CLIC_SiD: Larger material budget, increased single-point resolution in outer tracking and smaller number of active layers (no TPC) leads to increased resolution in barrel region
- Similar performance in forward region for the two detector concepts

IP-resolution vs. pixel size (CLIC_SiD)

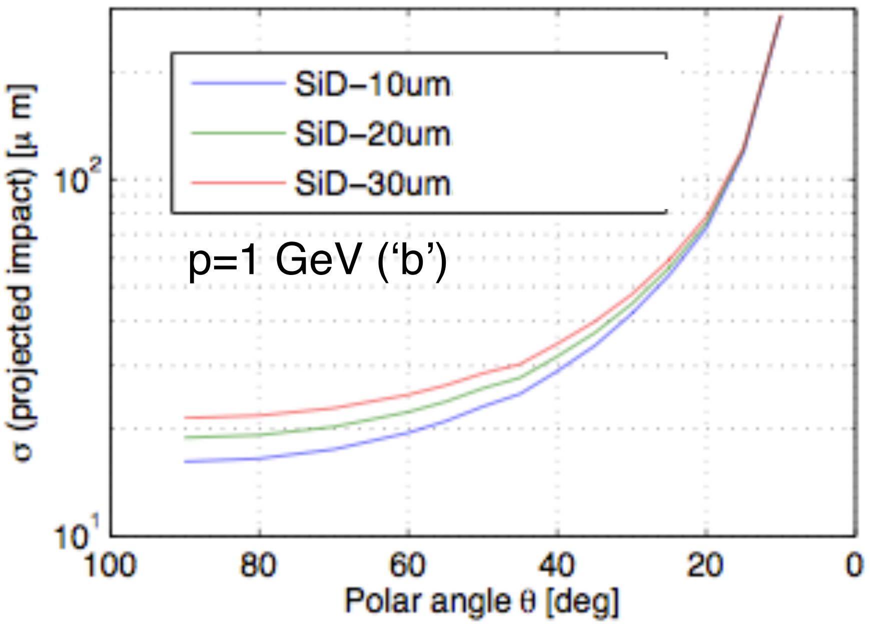
•How does the single-point resolution of the pixel detectors affect the IP resolution?

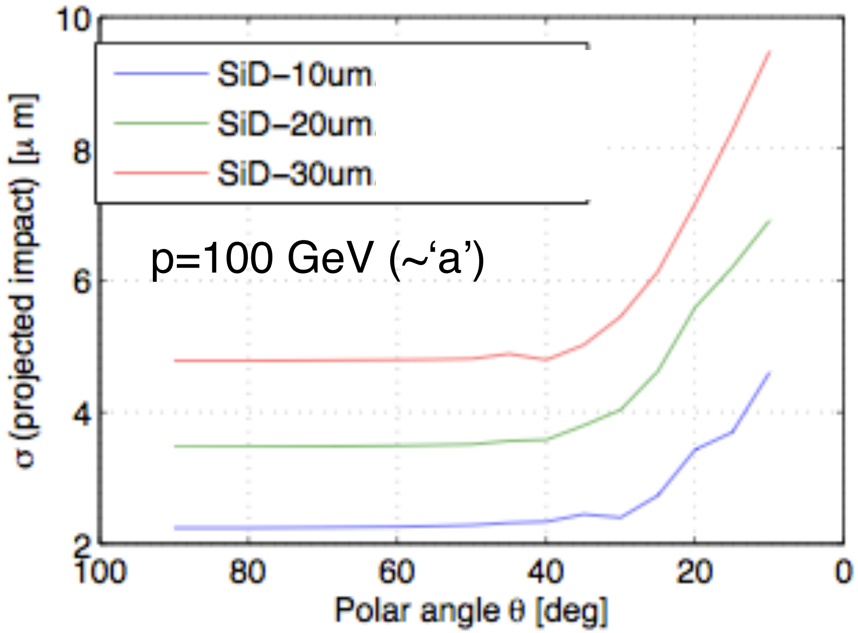
→ change pixel size in CLIC_SiD, maintaining the digital readout:

10 μm → σ_{sp}~2.9 μm

20 μm → σ_{sp}~5.8 μm (default for CLIC_SiD)

30 μm → σ_{sp}~8.7 μm





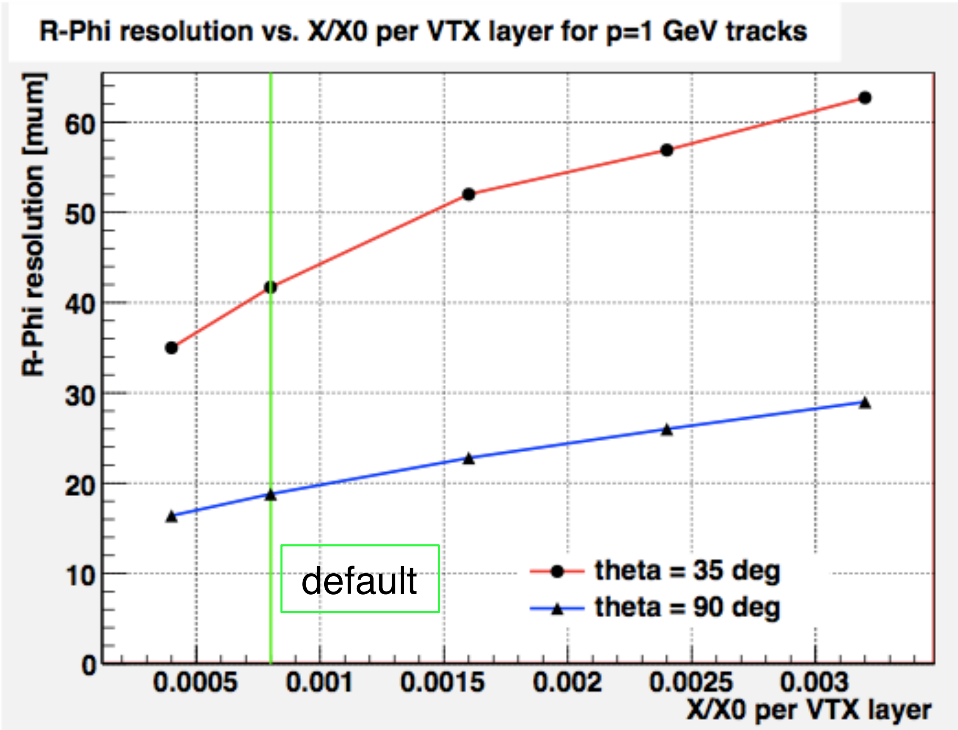
•As expected, the change by ±10 μm in single-point resolution affects ‘a’ more than ‘b’:

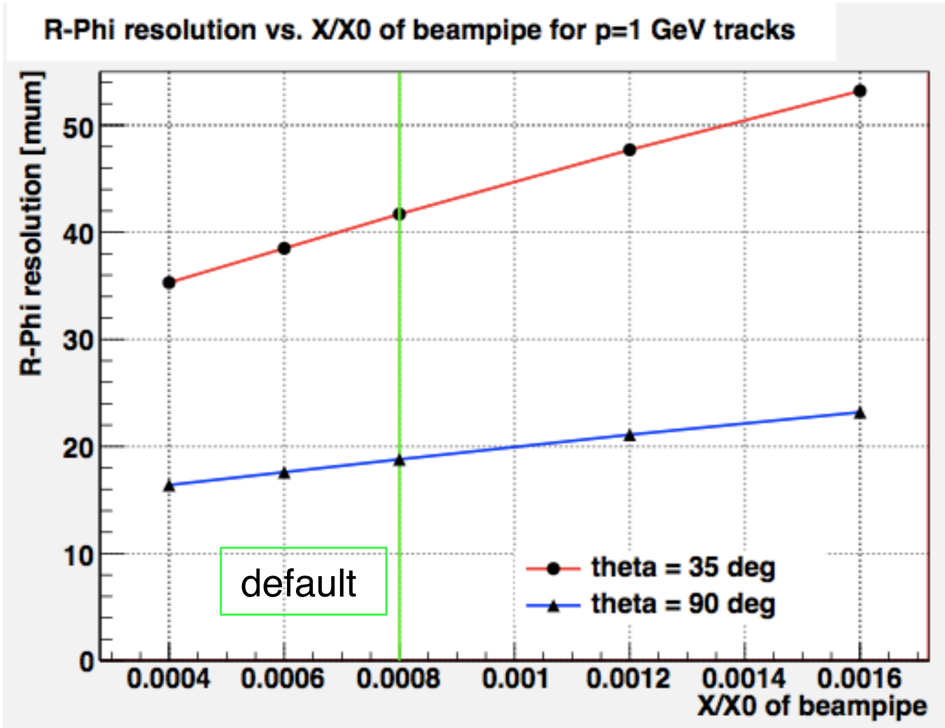
‘a’ ~ ±40%, ‘b’ ~ ±15% (in barrel region)

•Little change in forward region for low momenta (dominated by multiple scattering)

IP-resolution vs. material budget (CLIC_ILD)

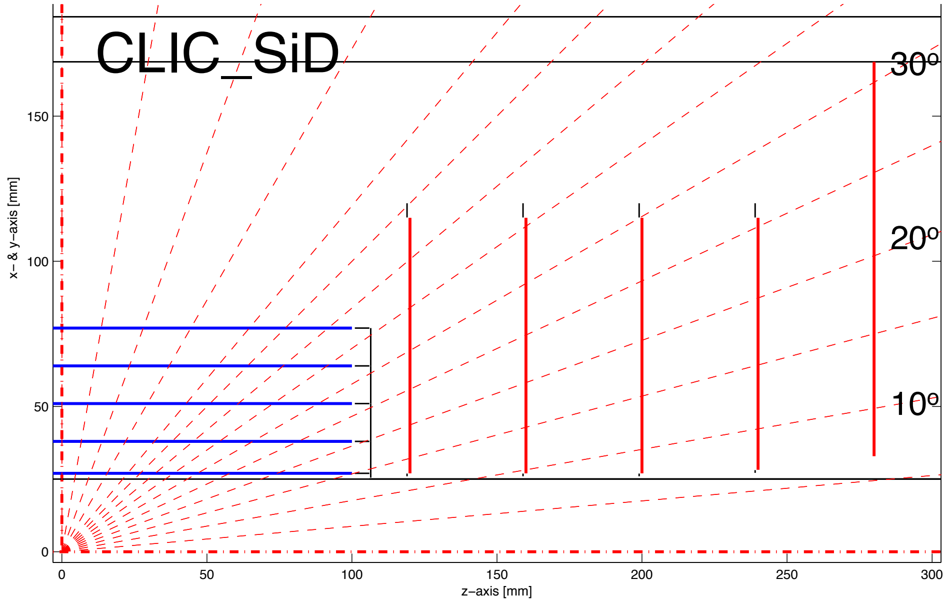
•How does the material budget inside the pixel detector affect the IP resolution?
→ Changed material in VTX-layers and in beam pipe and looked at projected IP resolution for two different theta angles

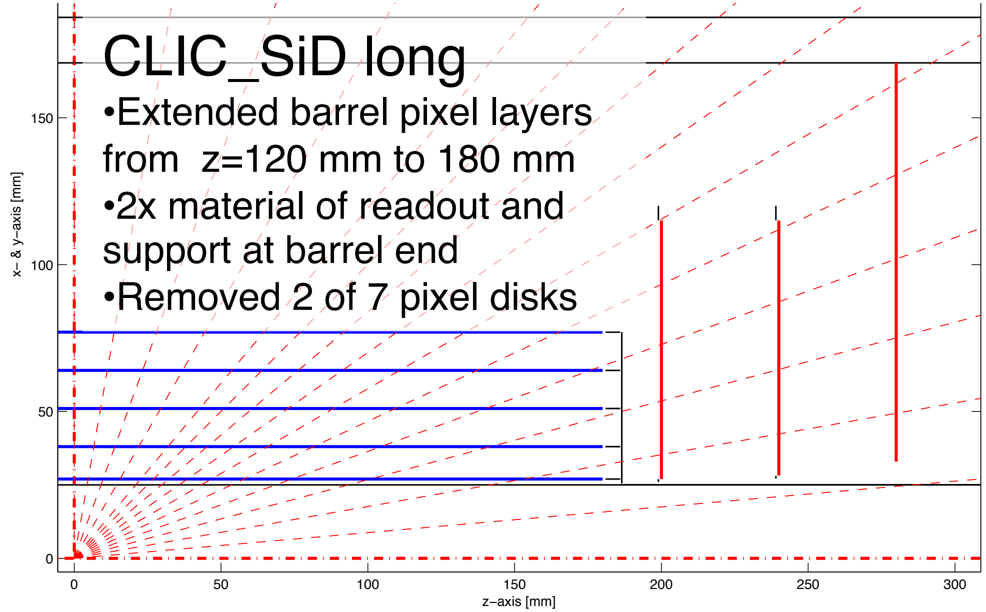




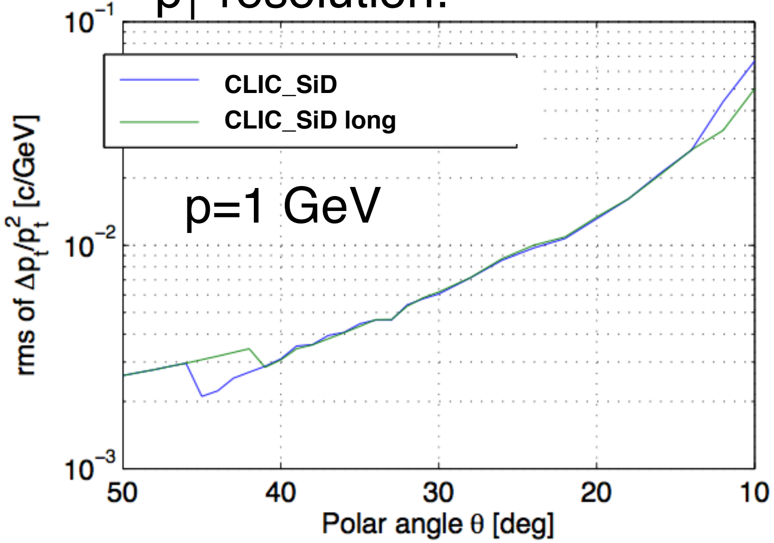
•~20-30% worsening for x2 more material w.r.t. (optimistic) default
•Results will help to assess the effect of different technology choices

Length of barrel section (SiD)

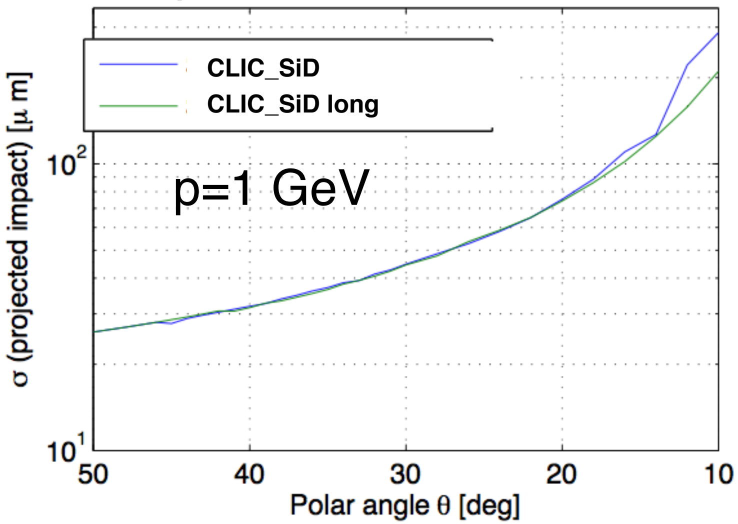




p_T-resolution:



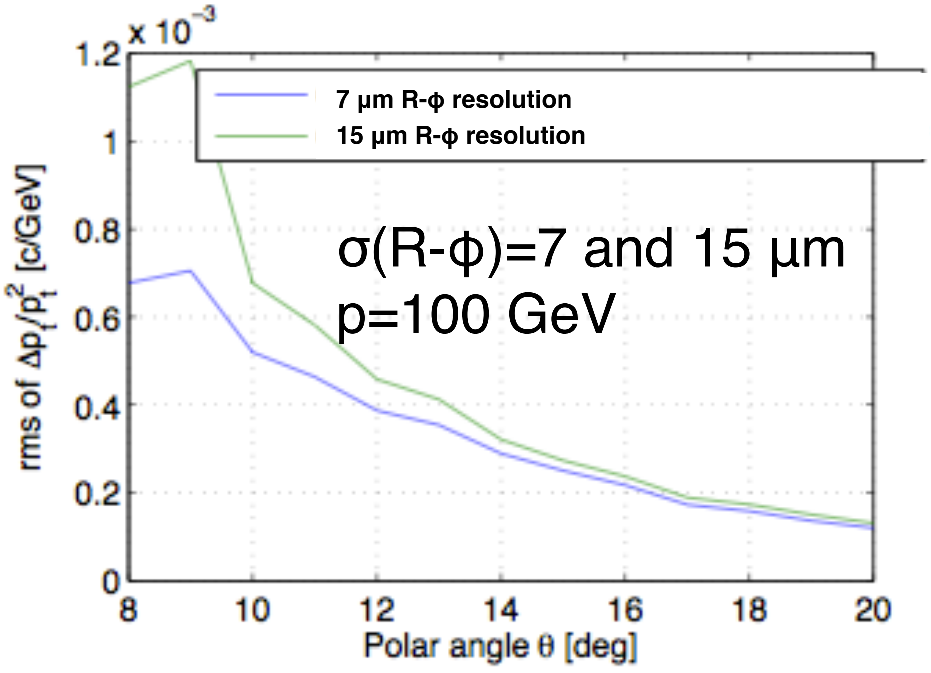
R-phi IP resolution:

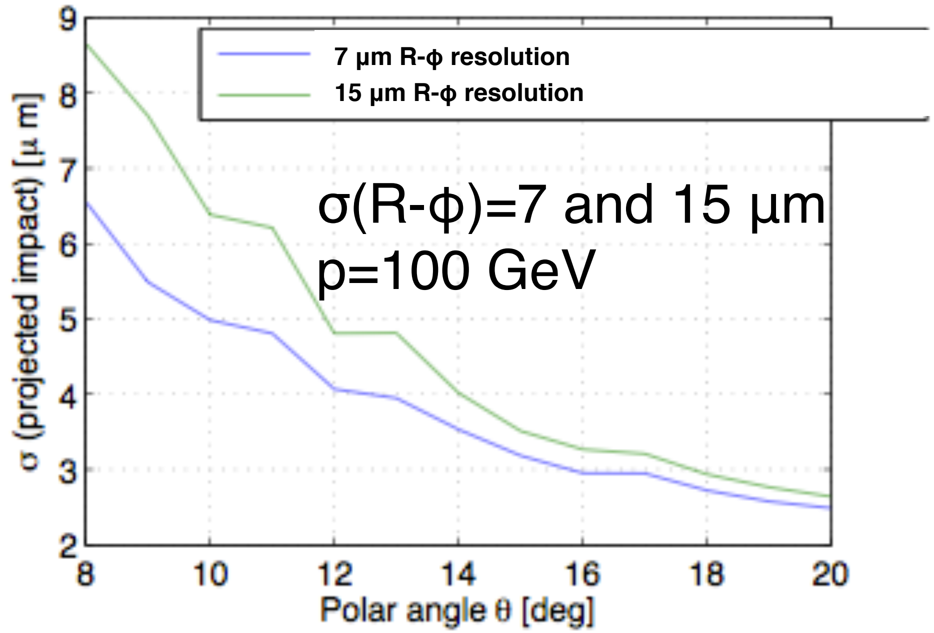


- Long barrel improves p_T and IP resolutions for very forward region $\theta<15^o$ (less material in front of first hits)
- Long barrel worsens p_T-resolution for $40^o<\theta<45^o$ (missing 1st pixel disk)

Single-point resolution of forward tracker (ILD)

(Results obtained with older version of geometry)





•Doubling the R-phi single-point resolution of the FTDs worsens p_T resolution at theta=10° by ~30%

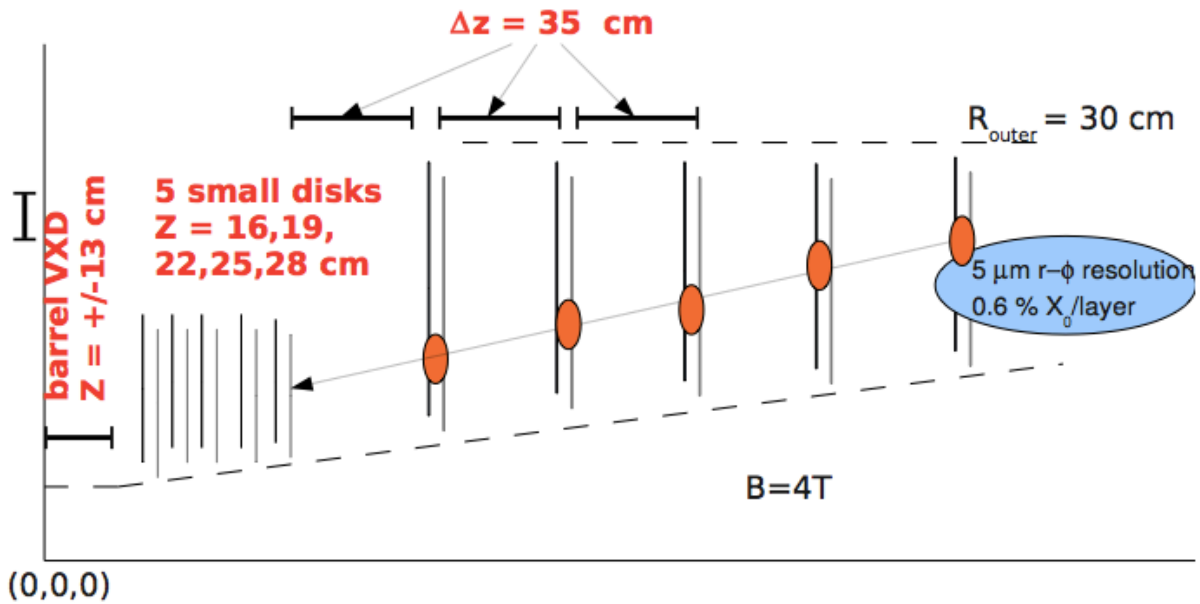
•Similar effect on impact-parameter resolution

→ Need to maintain a good single-point resolution in the forward tracker

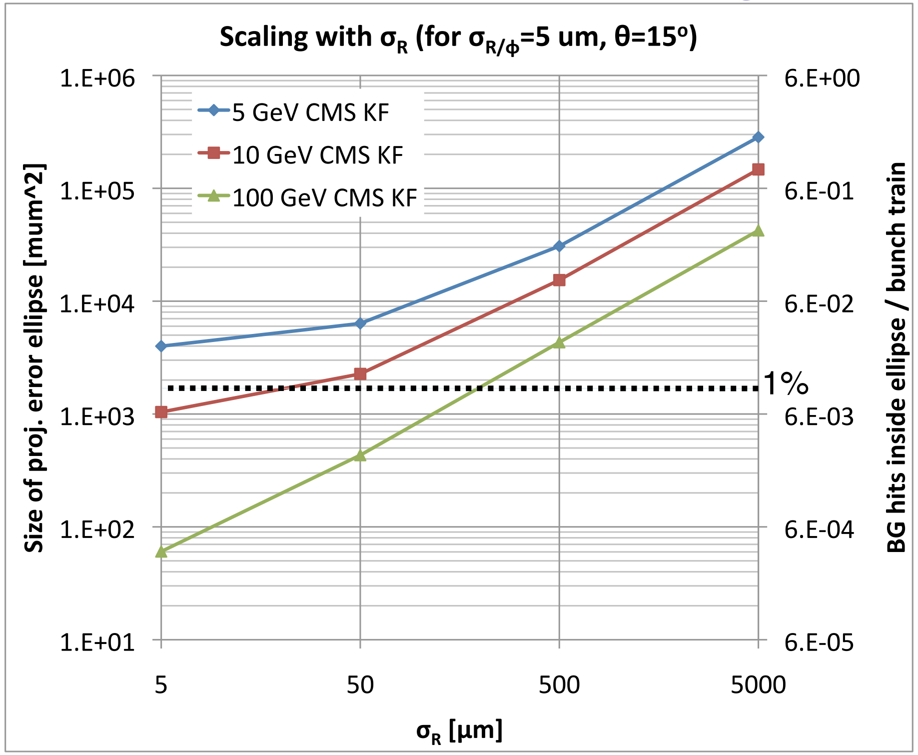
Forward tracking layout optimization (CLIC_ILD)

- R/phi measurement sufficient to measure momentum, however: need R-measurement for track finding/extrapolation
- Resolution in R/phi and R can be adjusted using strip layers with stereo angle
- Stereo angle defines relative resolutions, size of track-extrapolation error and number of ghost hits

- Track finding at CLIC will suffer from high density of background hits (~0.04 hits / mm^2 / ns in innermost layers)
- Track extrapolation from layer to layer requires negligible number of background hits within projected error ellipse
- Used dedicated ILD-like test geometry to optimize stereo angle and layer placement



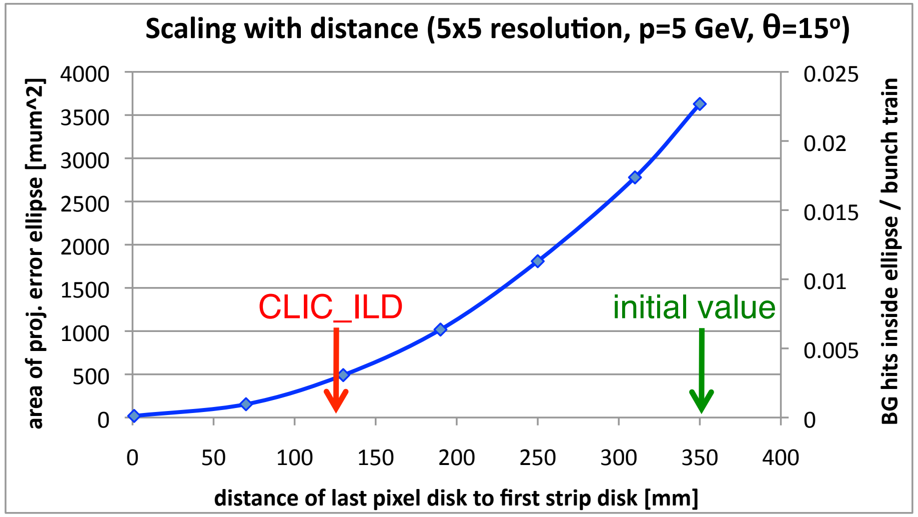
Forward tracking layout optimization: results



Dependence on R-resolution:

- Assume 0.04 hits / mm^2 / ns from e^+e^- pairs
- Look at size of projected error ellipse and expected number of background hits for different R resolutions and track momenta
- Number of background hits unacceptably high for large values of σ_R

→Need stereo layers with σ_R~50 μm



Dependence on distance in z-direction:

- Varied distance between pixel and strip layers
- Size of error ellipse increases ~quadratically with distance

→ added extra strip layer for additional safety margin

Conclusions/Outlook

- Presented preliminary tracking layouts for CLIC_ILD and CLIC_SiD

- Fast simulation studies used to assess dependence of detector performance on technology and layout choices

- Expect further validation results to come with large-scale MC simulation studies in the context of the CDR:
  - Track reconstruction in the presence of backgrounds and inside dense jets
  - Effect of resolutions on b-tagging efficiency and fake rates (cf. first results in talk by Marco Battaglia on b-tagging in Performance session tomorrow)

- More details and discussions in regular tracking and VXD meetings:

  LCD-WG-3: http://indico.cern.ch/categoryDisplay.py?categId=2842

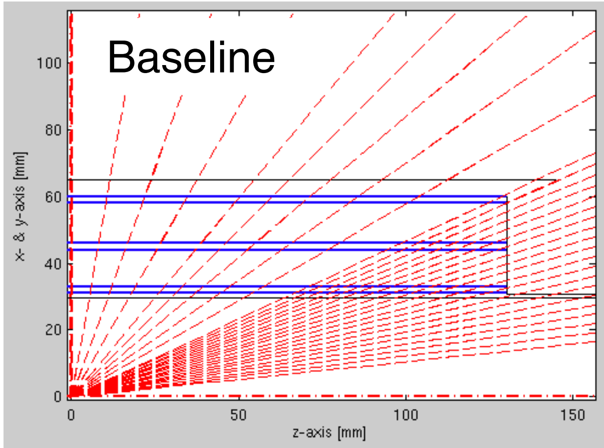
  LCD-WG-4: http://indico.cern.ch/categoryDisplay.py?categId=2843

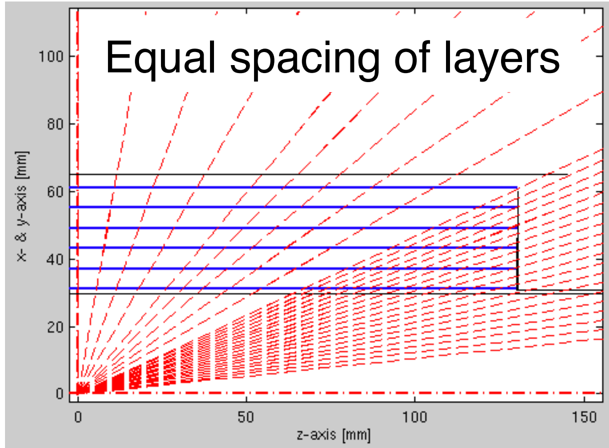
Backup Slides

Barrel layer placement (ILD)

Double vs. single layers:

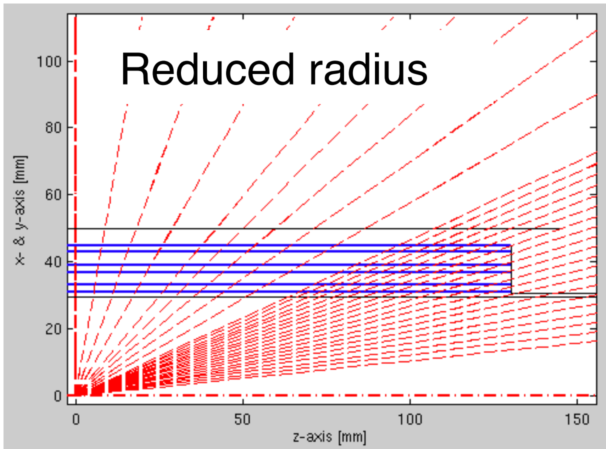
- Double layers may help to **reduce material** for support
- Also adds **redundancy** and possibility to **reject background** coming from outside the IP region
- Disadvantage: will **lose hits** from late decays (behind first double layer)

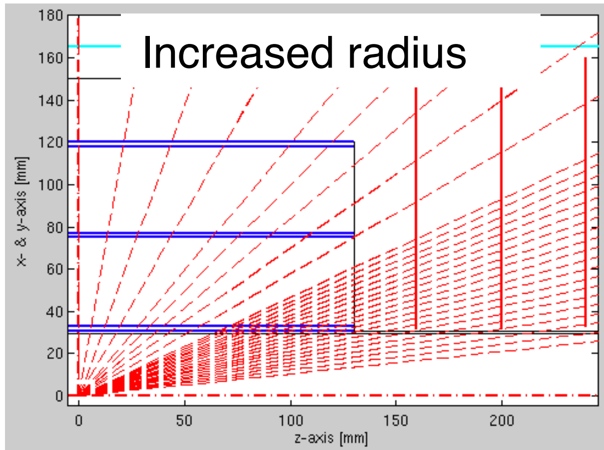




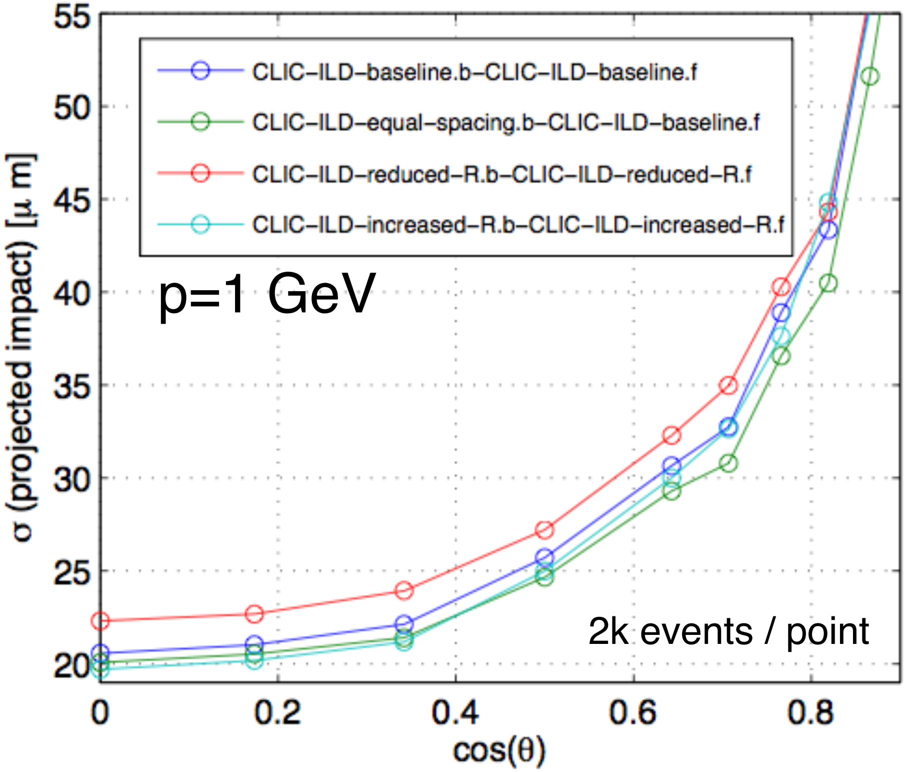
Compact vs. stretched out:

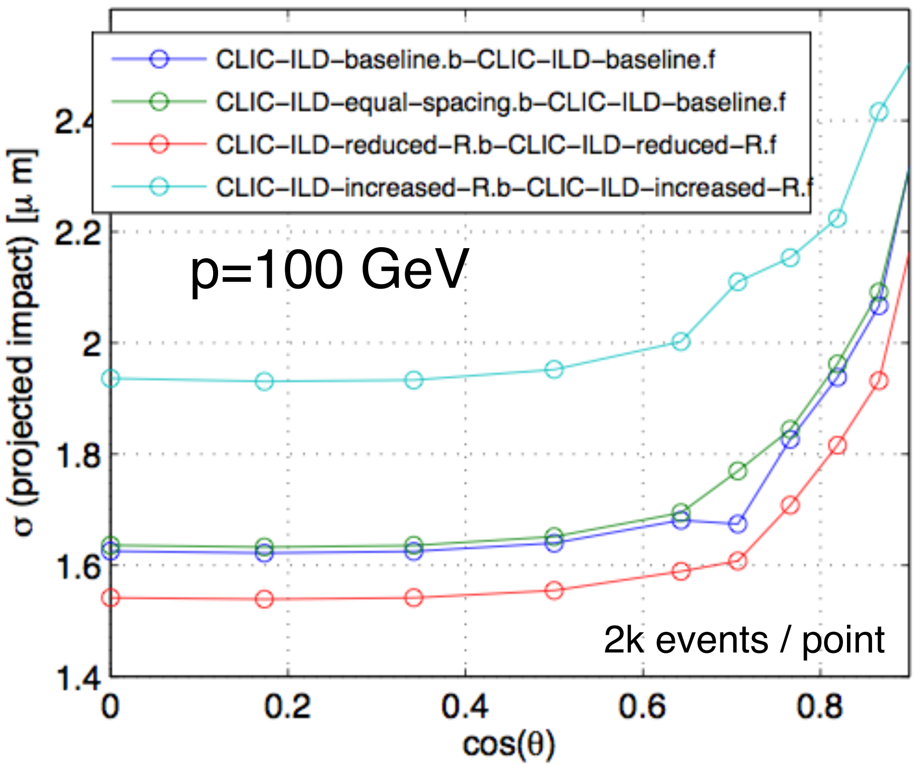
- Compact design leads to more hits closer to IP, improving resolution for high momentum tracks
- Disadvantage: material moves closer to IP, worsens effect of **multiple scattering** for outer tracker





Barrel layer placement: results



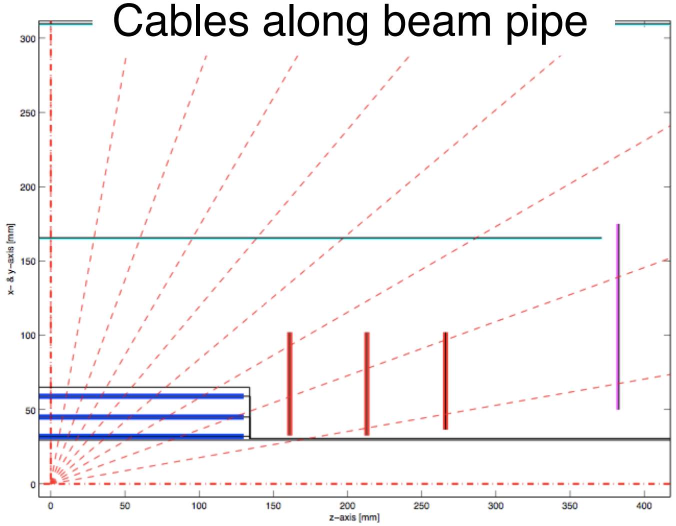


Equal spacing of layers: slightly better for 1 GeV, slightly worse for 100 GeV
Reduced radius: worse for 1 GeV, better for 100 GeV
Increased radius: slightly better for 1 GeV, worse for 100 GeV

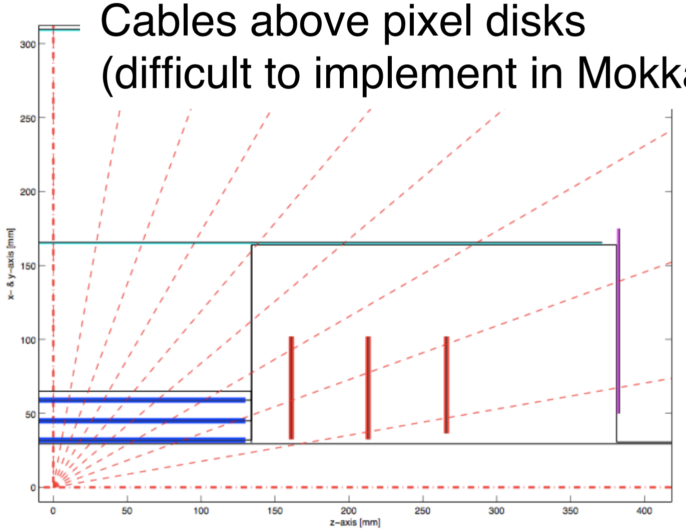
•double layers show similar performance compared to single layers
→Will use this for CLIC_ILD, to assess additional benefits in full simulation
•no significant improvement expected from different radial arrangement of barrel layers

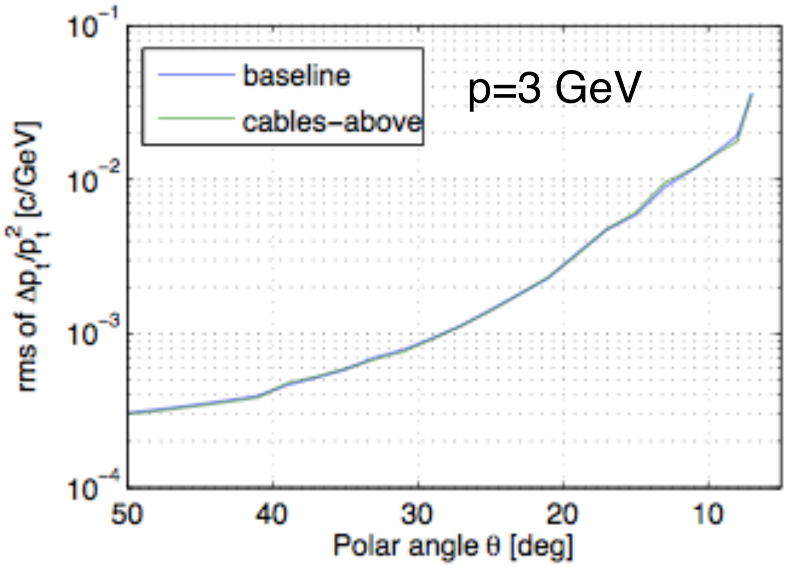
Cable Routing Options (ILD)

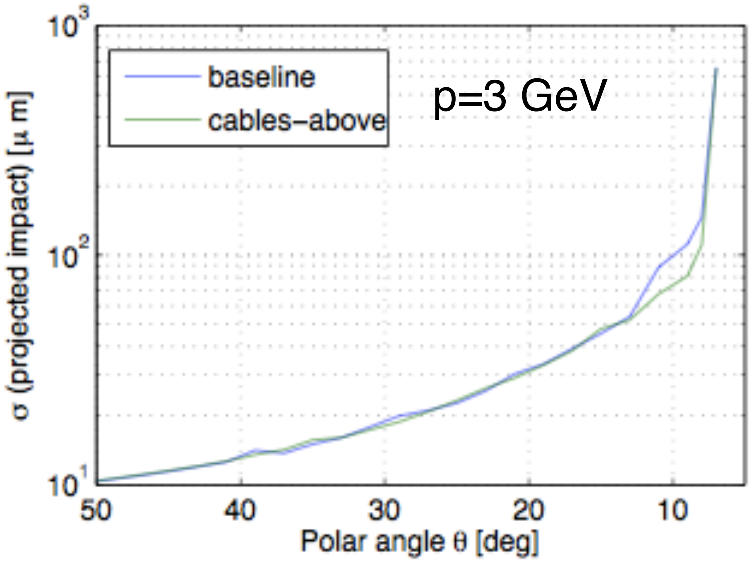
Cables along beam pipe



Cables above pixel disks
(difficult to implement in Mokka)







- ➢Routing cables above FTD Pixel Disks improves IP resolution in this region