Optimization of the muon & yoke system for CLIC

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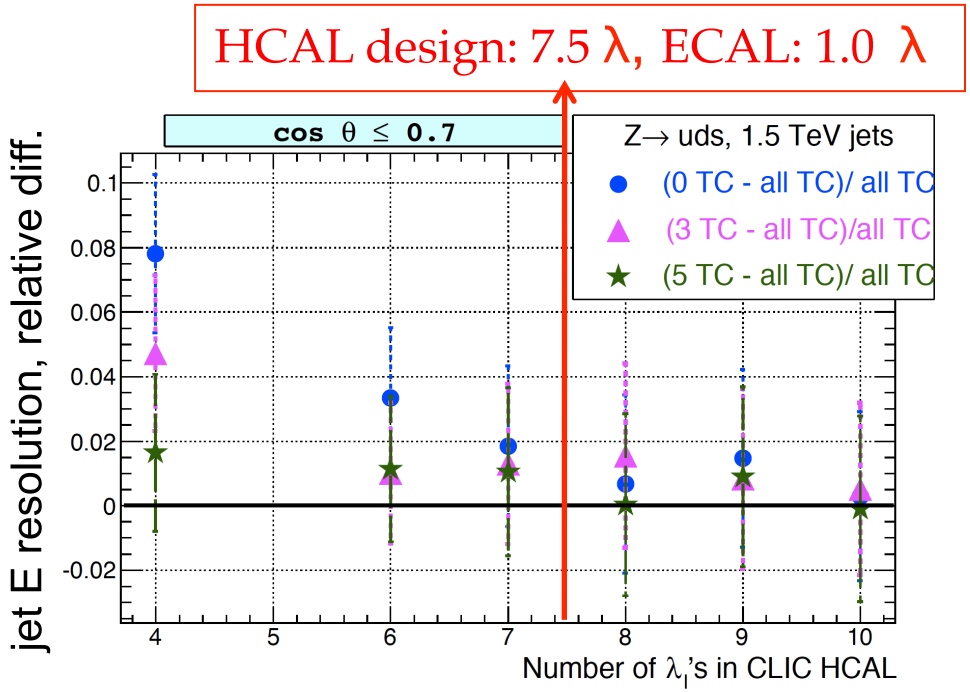
- Tailcatcher
- Muon layers layout
- Readout cell size
- Yoke engineering design
- Resulting magnetic field

Tailcatcher performance



A. Lucaci-Timoce

The muon system must also perform as a tailcatcher to the HCAL.

- Jet energy resolution studied with different HCAL- and tailcatching depths
- For 1.5 TeV jets, improvement can be seen with a tailcatcher. Yet for more than 6λ, three layers is enough.

➢ Start yoke instrumentation with three sensitive layers.

Testing several detector layouts

To test models with different layouts of muon layers, one Mokka model was created with 18 layers at equal distances of 14 cm (10 cm steel, 4cm active layer)

- In the reconstruction step, layers can then be included/excluded.
  - 8 models with #layers varying from 7 to 17 were tested:

Model	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
7	X	X	X				X				X			X			X
8	X	X	X					X		X		X			X		X
9a	X	X	X				X		X		X		X		X		X
9b	X	X	X					X	X	X					X	X	X
11	X	X	X				X	X		X	X		X	X		X	X
13	X	X	X		X	X		X	X	X		X	X	X		X	X
15	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X
17	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Always 3 layers for the tailcatcher

Performance analysis setup

To test the new algorithm we use $Z^* \rightarrow bb \rightarrow \mu X$.

- Created 6000 Z^* (1.5 TeV) → bb, with at least one muon in final state.
- These b-jets have approximately the energy expected in 4b-jet final state events at CLIC.

Muons are reconstructed with the PandoraPFANew muon algorithm, with the steering parameters for the #layers relaxed.

- Only muons with $E > 7.5$ GeV and $\theta > 10°$ are considered;
  θ cut is to prevent poorer coverage in the very forward region from biasing the overall performance.
- A reconstructed muon is defined as matched to a true MC muon if:
  - Angle between momenta no more than 1°,
  - Reconstructed energy no more than 5% off from the true energy.

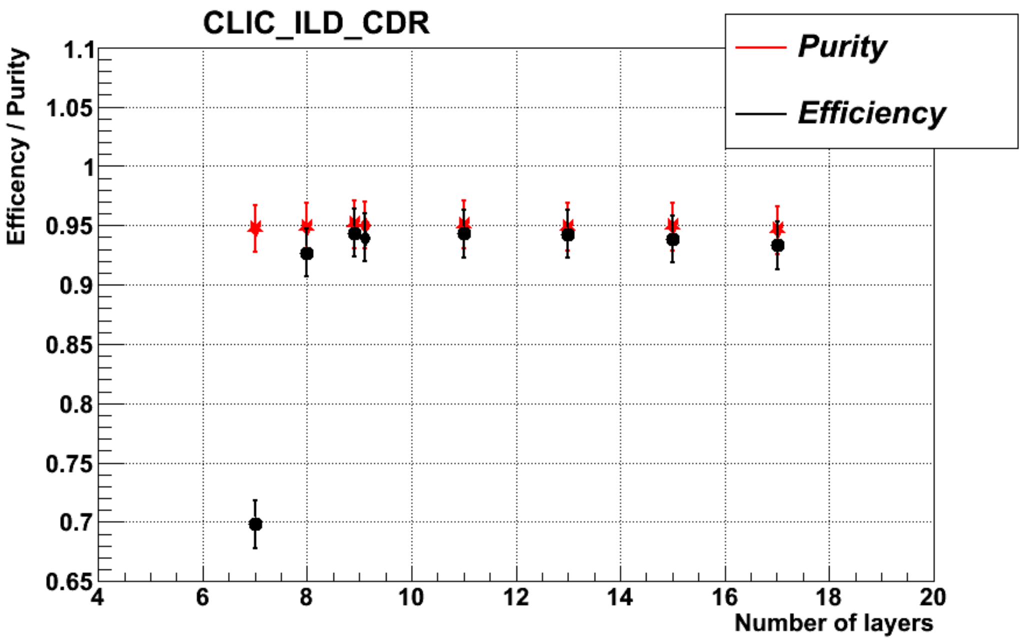
Details can be found in the, soon to be published, LCD-NOTE-2011-008:
[Muon System Design Studies for Detectors at CLIC]

Performance as function of #layers

For models with 8 or more layers, the performance is similar.

Two entries of 9 layers (with the first 3 layers always the same) have the same performance:

- One with 6 layers at equal distances
- One with 2 groups of three.



- Purity is independent of #layers. Efficiency drops rapidly with less than 8 layers.
  - Sharp decrease due to the clustering algorithm failing because of the large distance between the isolated hits. → Results depend on details of the reconstruction algorithm, so there is room for improvement.

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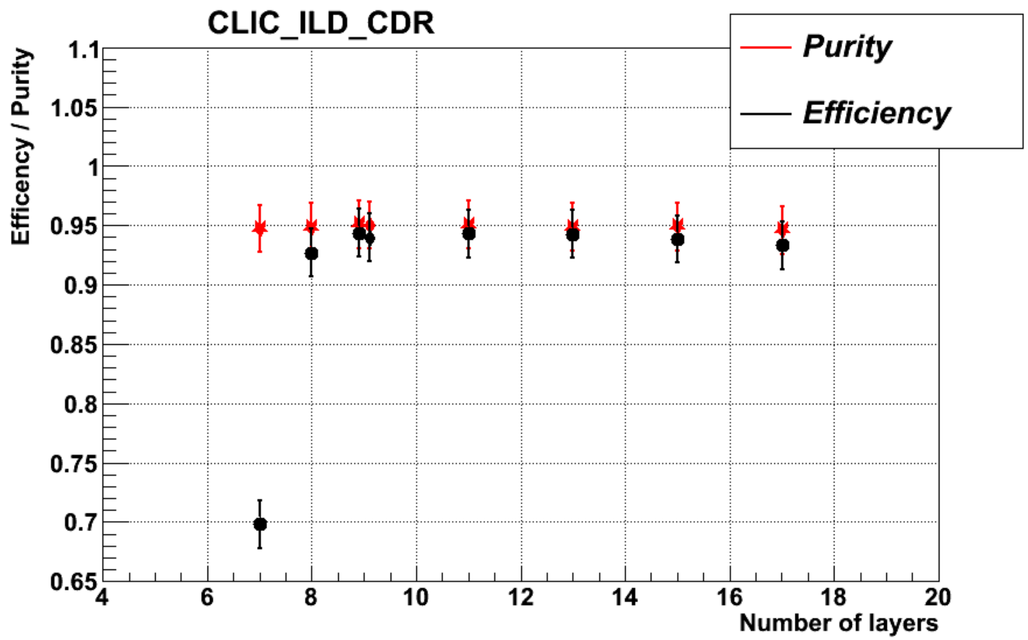


Model with nine layers, grouped in layers of three, is adopted for CLIC.

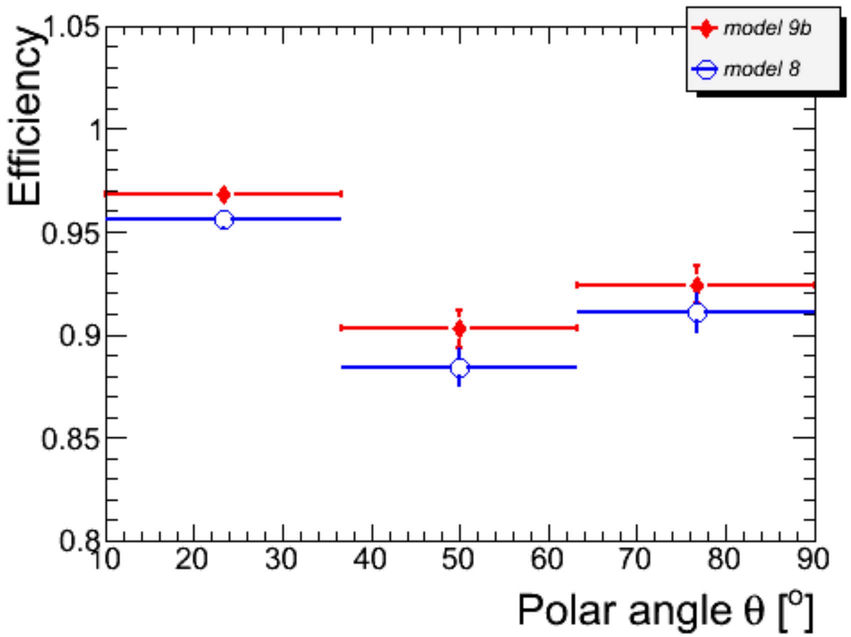
- The grouping leaves space for two thick (>50 cm thick) iron yoke plates, useful for the absorption of the inward magnetic forces.
- 3x3 layers satisfies the need for redundancy.

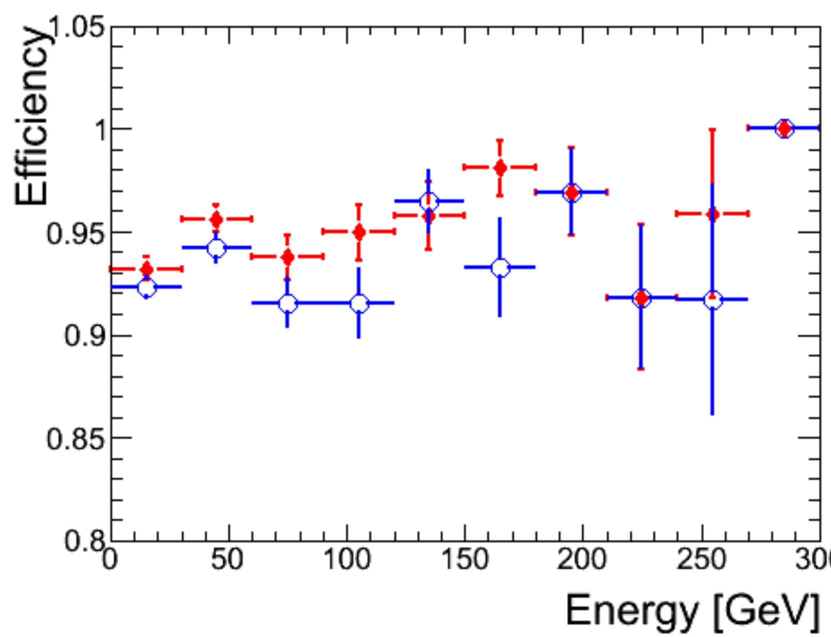
Performance as function of energy and θ

The overall results with 8 and 9 layers only differ slightly.

- Studying the performance as function of energy and θ shows that the difference is present over the full phase space.

  → Clearly systematic, and not a statistical fluctuation.

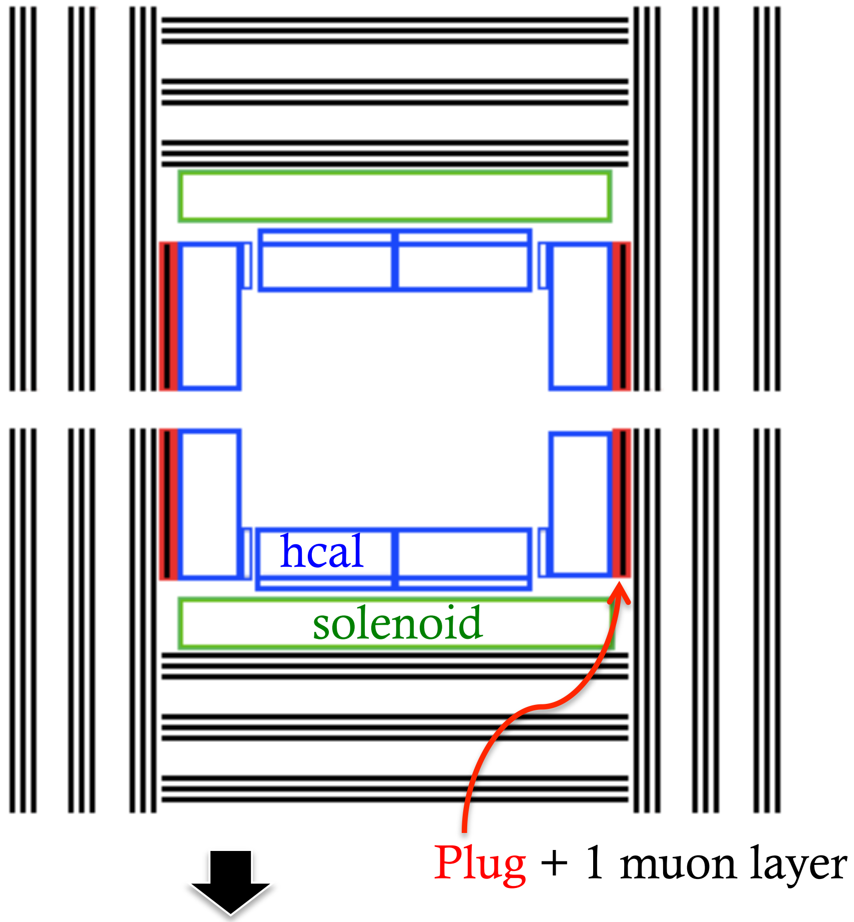




CLIC CDR detectors - full geometry

- ➢ Yoke barrel: 9 sensitive layers
  - Starting with active layer directly after solenoid
- ➢ Yoke endcap: 10 sensitive layers
  - Including single plug layer.

- Granularity: 3 x 3 cm^2 sensor size
- Sensor type: RPC (digital) or scintillators (analog)

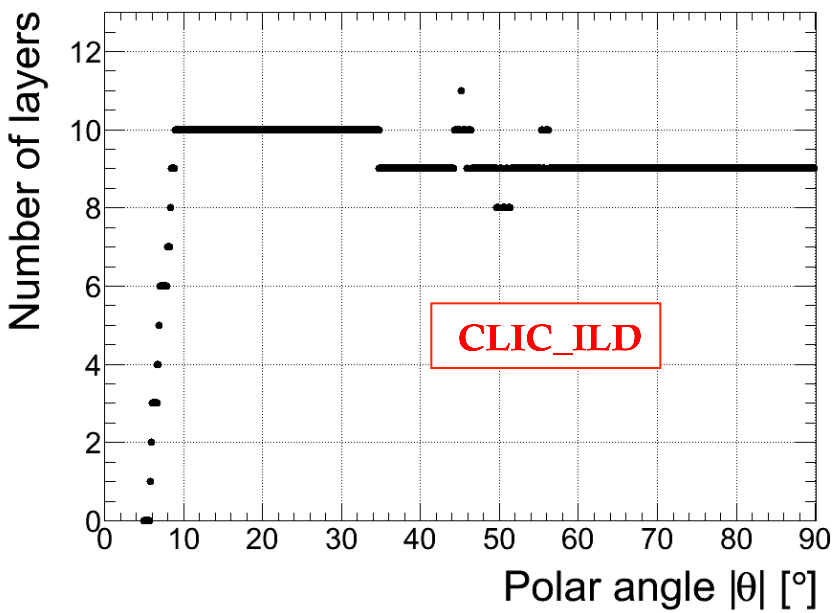


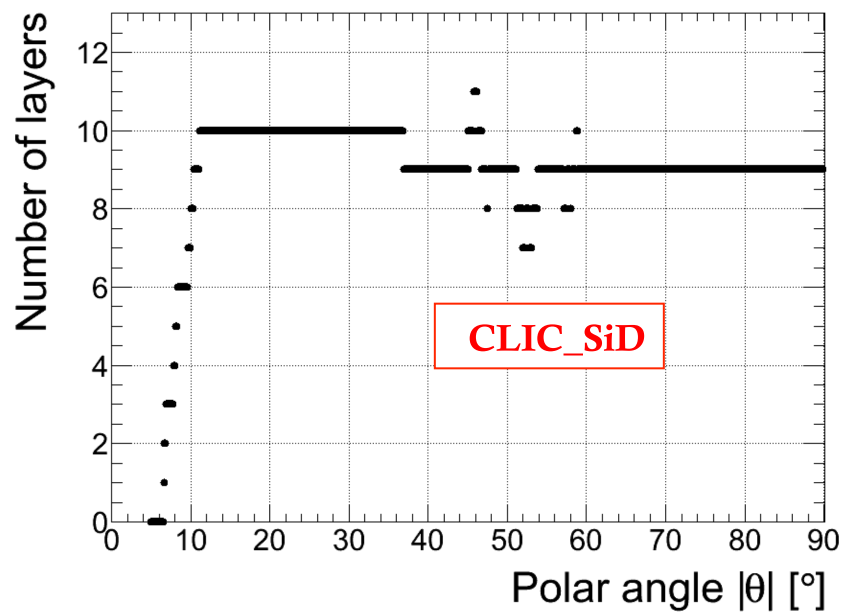
3x3 layered muon system, identical in CLIC_ILD & CLIC_SiD

Layer coverage

Count the #layers seen by a particle flying in straight line.

- As expected: 9 in the barrel, 10 in the endcap.
- For θ < 10° coverage drops rapidly.
- Optimization of coverage was performed only in CLIC_ILD detector.

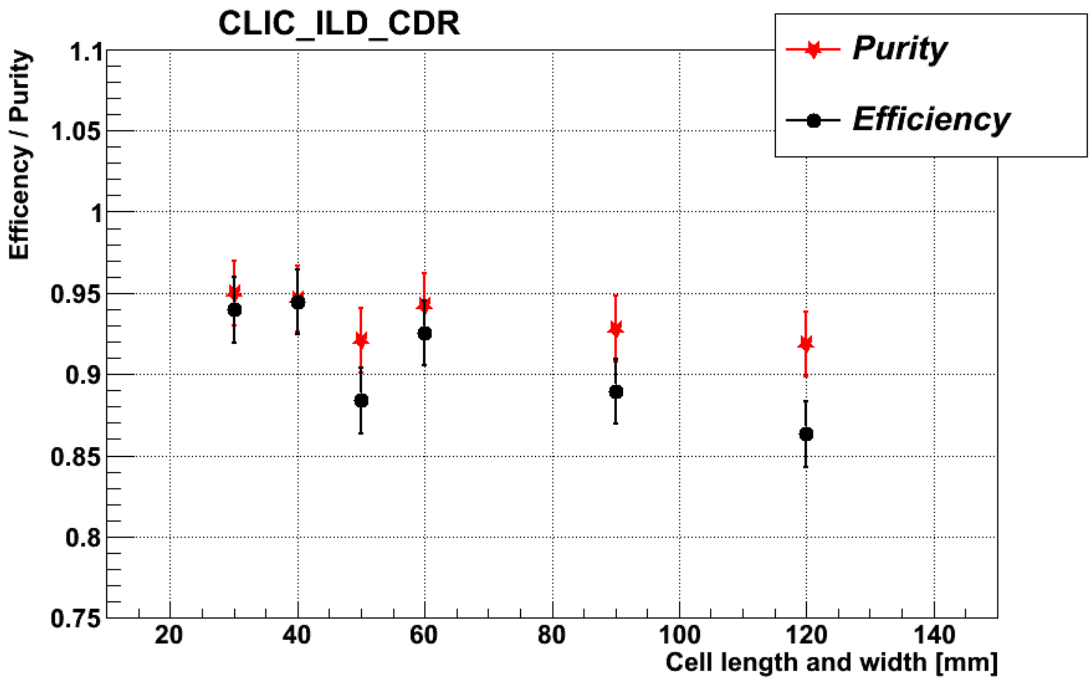




Performance dependence on readout cell size

By default the cell sizes in the muon layers is 30x30 mm^2, equal to the HCAL cell sizes. → Tested whether these can be made larger.

- Made 6 CLIC_ILD Mokka models with increasing cell sizes.
- Extracted the overall efficiency and purity.

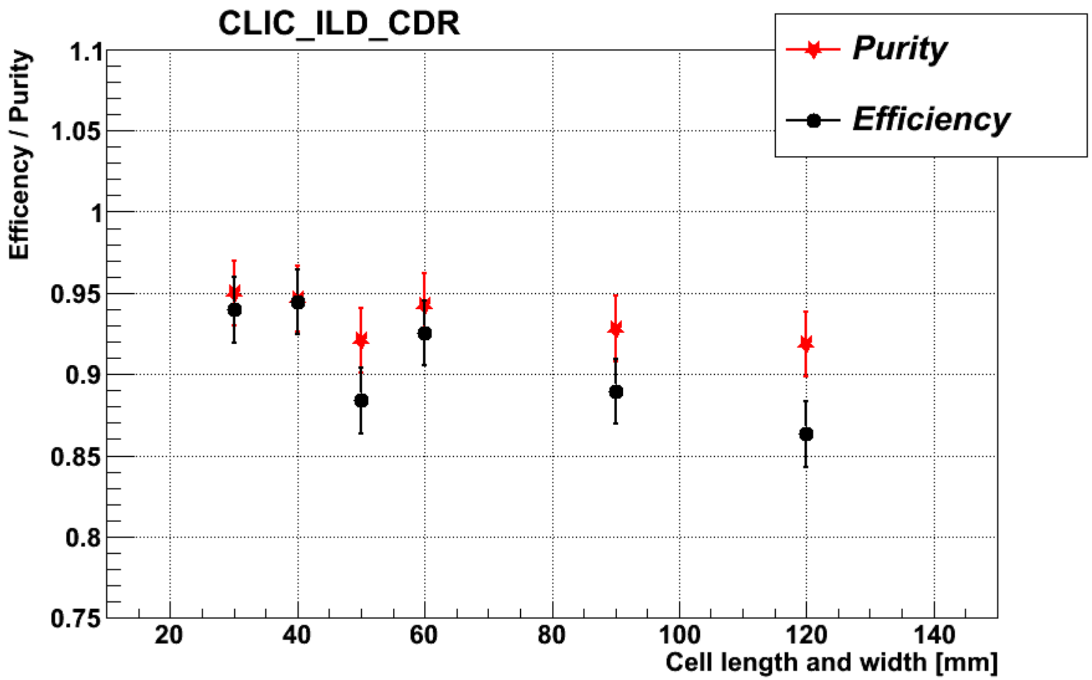


Performance dependence on readout cell size

Purity is less affected. Efficiency however has counter-intuitive results.

- $40x40\ mm^2$: results in similar performance and is a good option.
- $50x50\ mm^2$: performs worse than $60x60\ mm^2$. Unclear why.

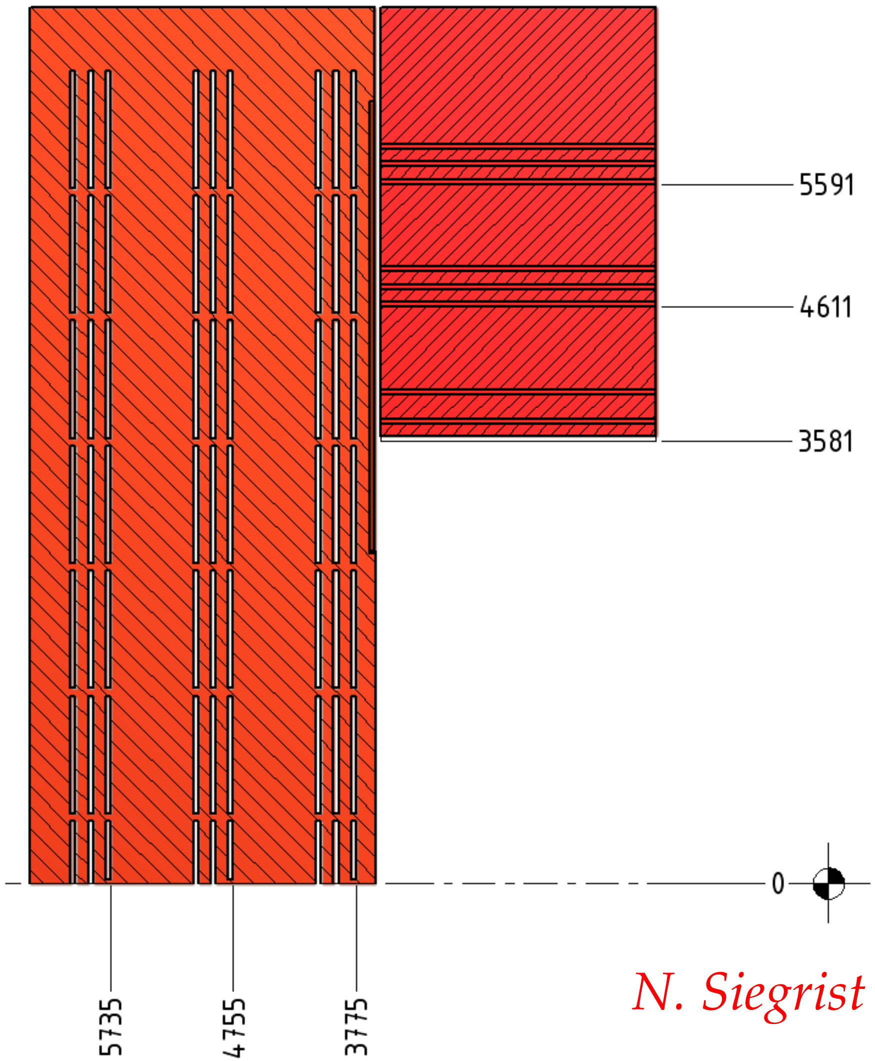
Occupancy due to beam halo muons: flux is high, to be taken into account before deciding on larger cells.



Implementation in SiD engineering design

Designs of CLIC_ILD & _SiD are very similar:

- The design foresees endcaps built out of large horizontal blocks, with each 3 slots for muon sensors. Their layout is chosen such as not to create gaps pointing to the IP.
- The inner most barrel layer starts directly after the solenoid, before the first iron yoke plate.
- For now the 3x3 layout, as optimized for the CLIC_ILD, is also applied to CLIC_SiD.
  - ➢ To keep magnetic stray field to a minimum a thick external yoke plate is foreseen in CLIC_SiD.



N. Siegrist

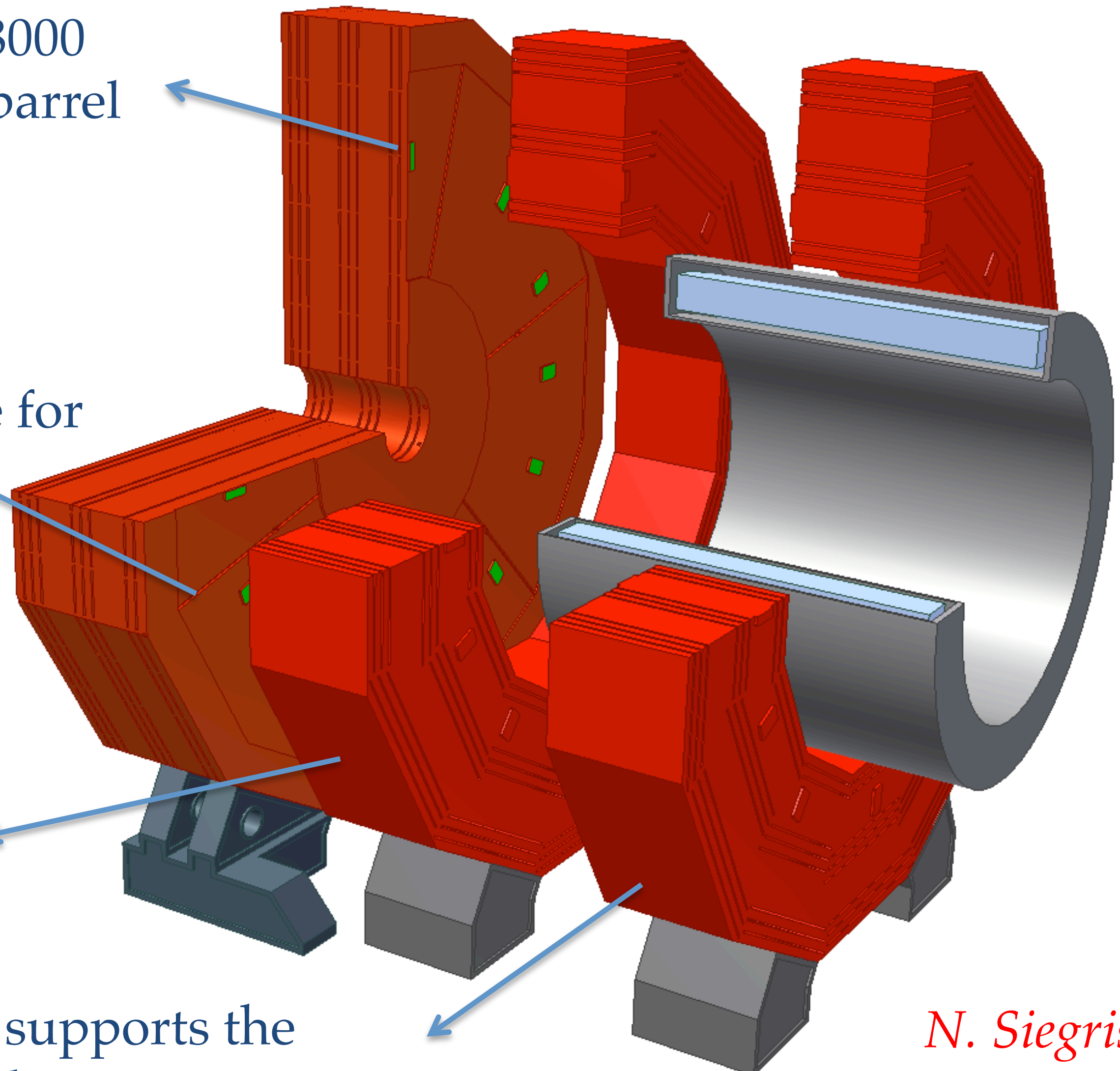
Implementation in SiD engineering design

Z-stops, to transmit the 18000 tons of force through the barrel

Channels in the iron yoke for alignment equipment

Segmentation of the barrel in 3 parts (only 2 shown) for assembly / disassembly

Middle barrel ring supports the coil, calos & inner detectors.



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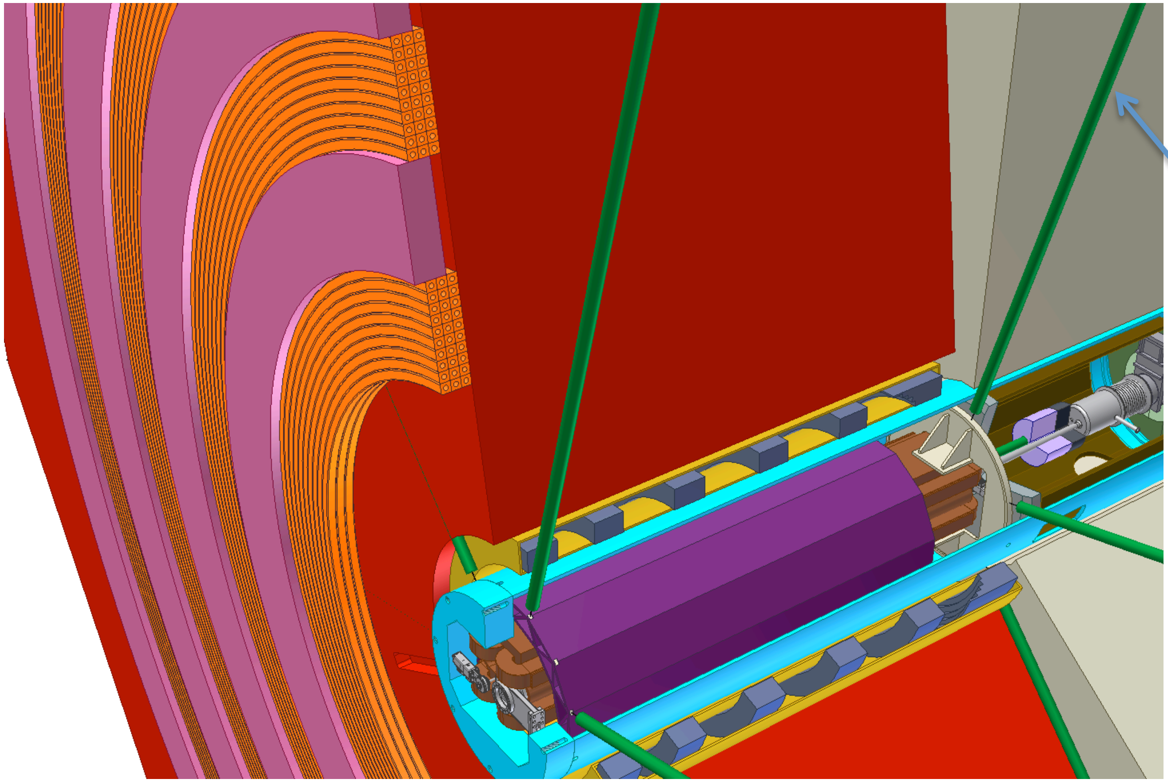
Yoke endcap in detail

The cavern at the IP is made as small as possible (along the beamline) to have the support tube for the QD0 magnets as short as possible.

- CLIC_ILD has a longer coil, therefore less space for yoke endcap.
- To keep the magnetic stray fields to a minimum, the small gap between tunnel wall and endcap is equipped with end-coils.

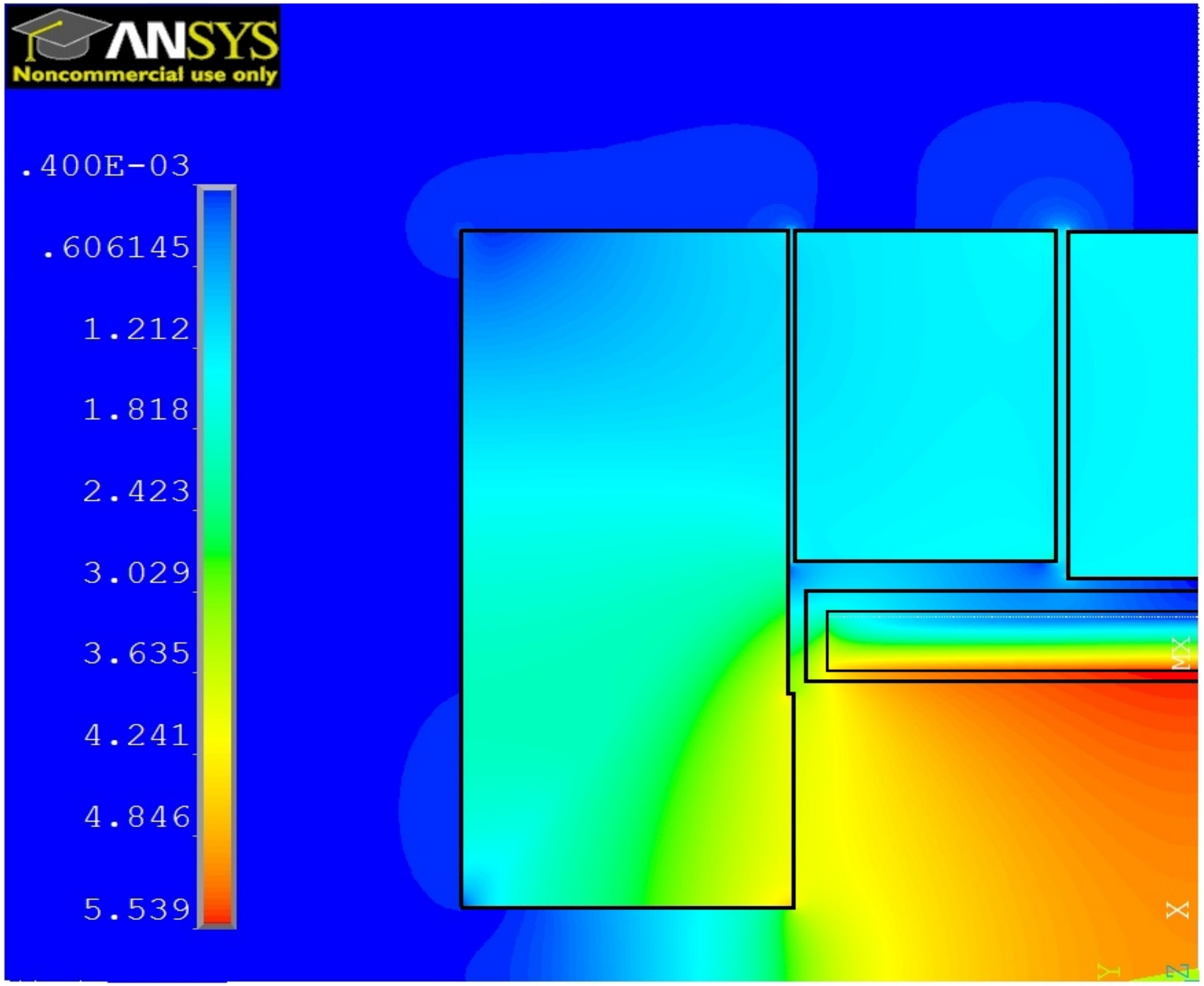


spokes for allignment

N. Siegrist

CDR magnetic field

With a 5T field & 100% iron assumption of the yoke:



Benoit Cure

Conclusion

After studying various layouts, a muon system of 3x3 layers has been adopted for both CLIC_ILD & _SiD for best muon ID performance.

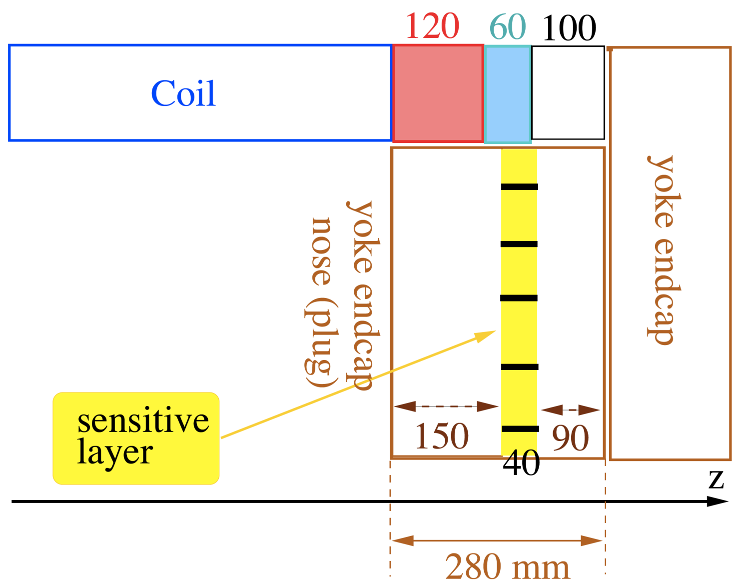
- Different readout cell sizes have been studied: larger cells up to 40x40 mm^2 are an option.
- Chosen layout helps in creating thick yoke plates for strength.
- Size of yoke system (& endcoils in CLIC_ILD) ensure required low magnetic stray fields. (50 Gauss at 15 m)

The detector studies for ILC and CLIC are largely overlapping.

- Work was done on the CLIC muon system for the CDR which is of potential interest for the DBD, and we can repeat this study for the DBD.

Backup slides

CLIC detector – yoke plug



In the CDR simulations it is implemented, but is not considered to be needed anymore.

Tailcatching in the endcap

- Subtlety: in the endcap there is always (in these studies) one plug layer between HCAL & muon system.

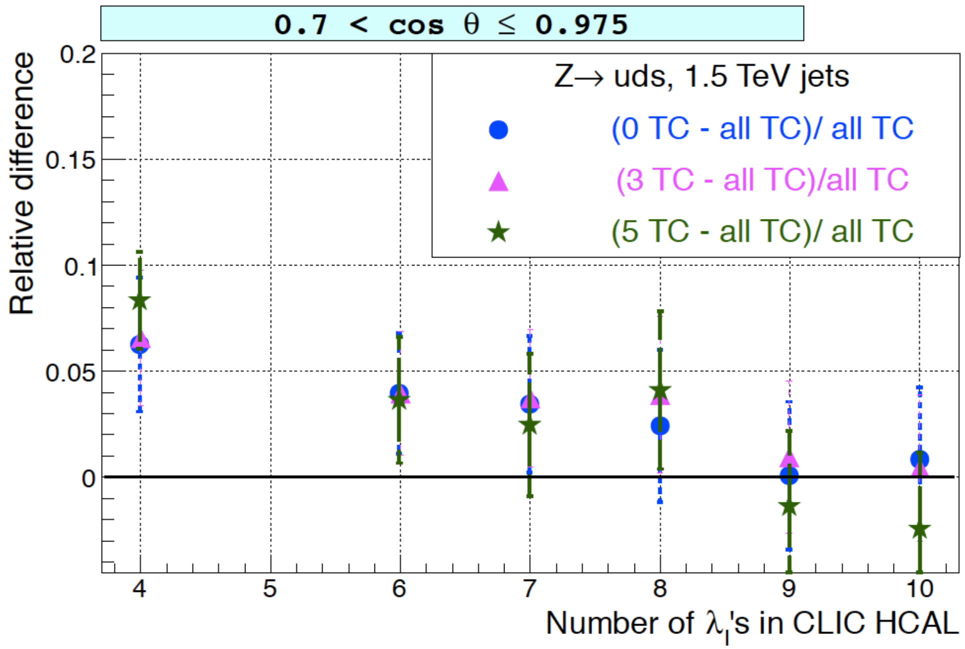
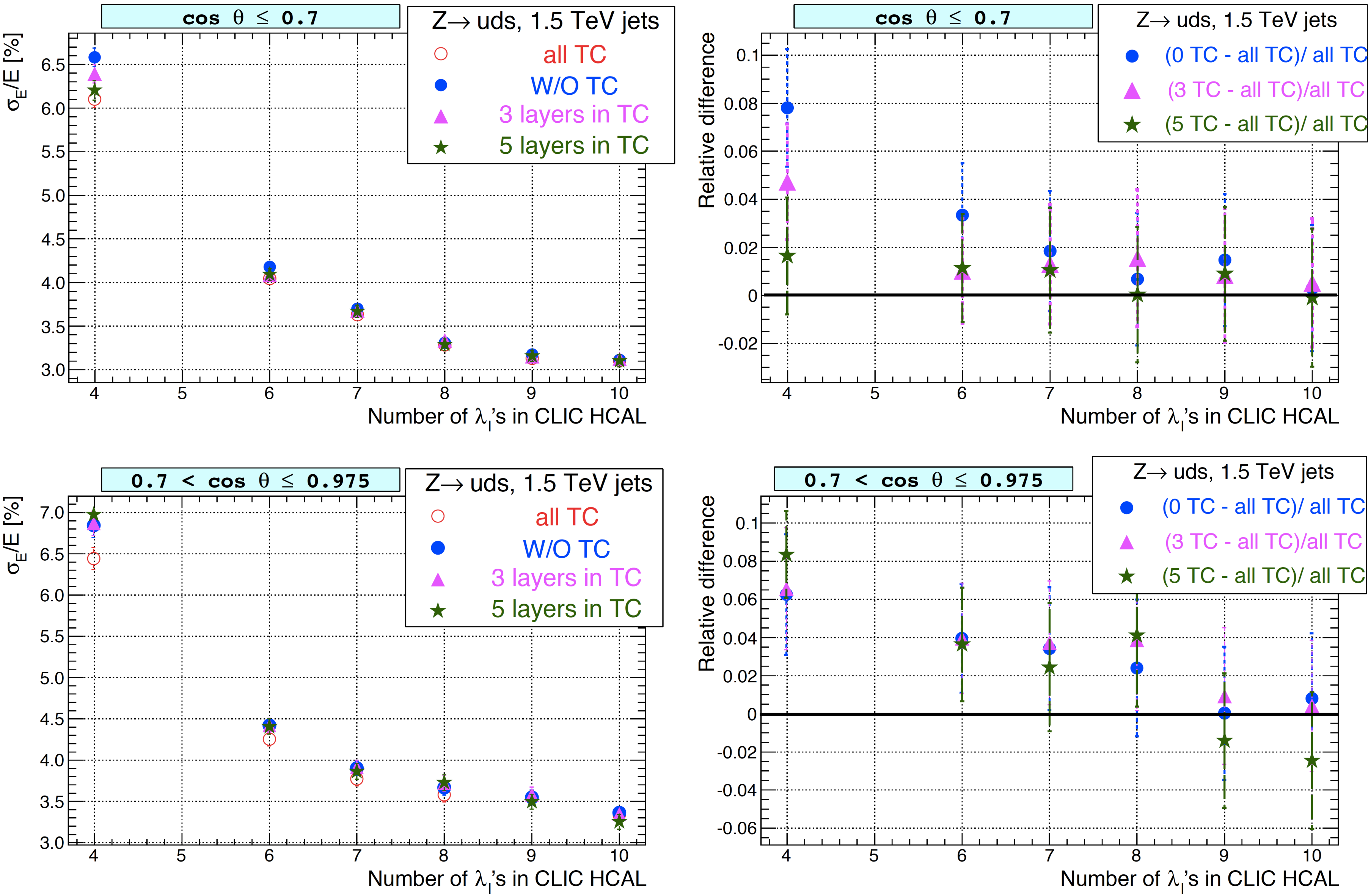


Figure 1: *The jet energy resolution as function of the hadronic calorimeter depth in the barrel* See 1st slide *and in endcap* See above *The resolution is given as the relative difference to a detector model including all muon layers.*

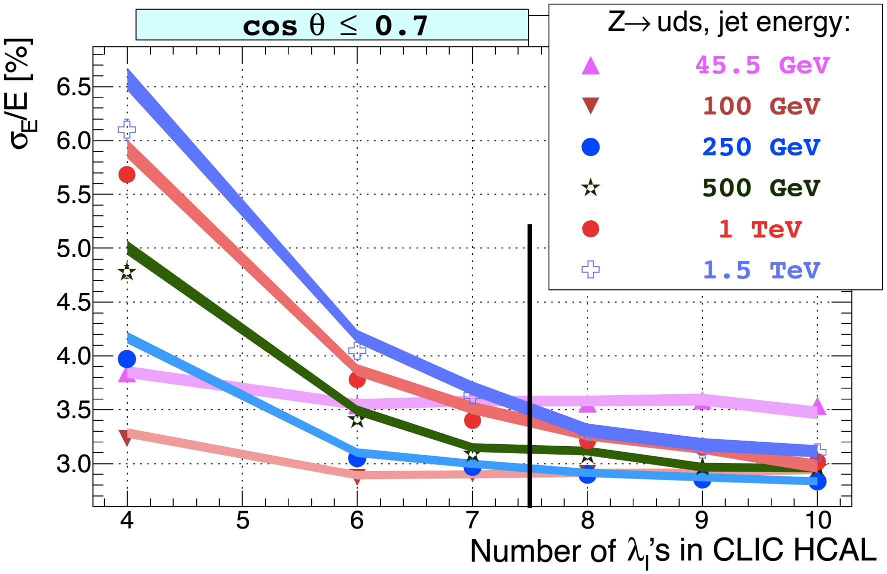
Tailcatching performance

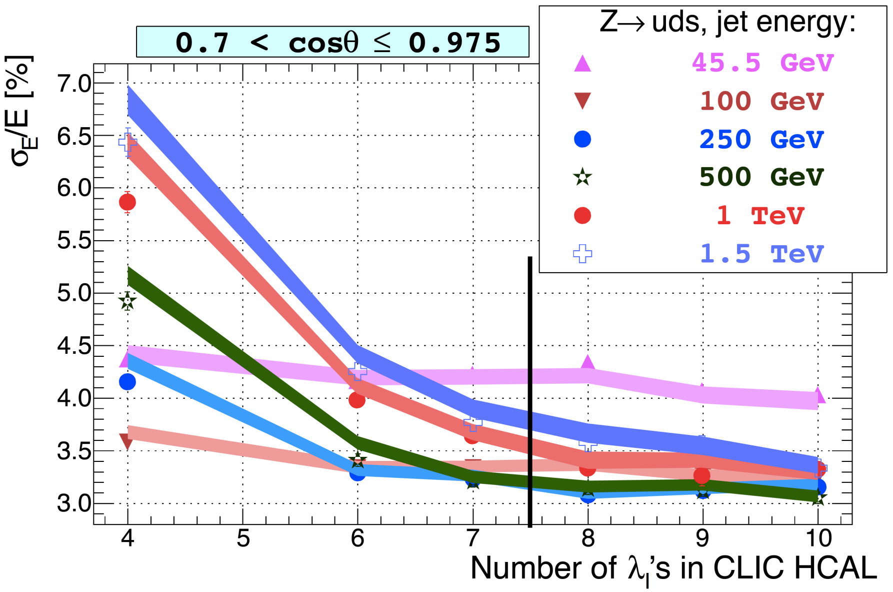
A. Lucaci-Timoce



Tailcatching performance

- Studies done with $Z \to uds$ events, based on a modified CLIC01_ILD model
- Jobs submitted to the GRID, via DIRAC
- Markers: with Tail Catcher
- Bands: WITHOUT Tail Catcher





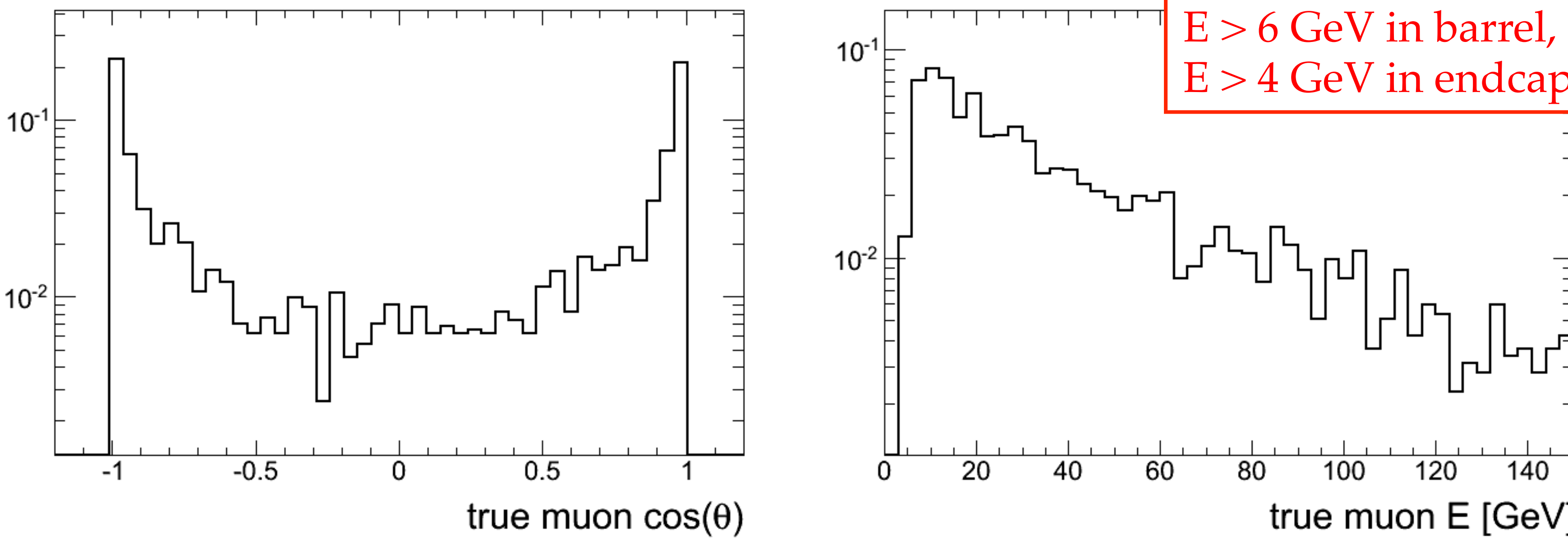
- Small influence of the Tail Catcher
- Final decision on HCAL depth: 7.5 λ_I

To test the new algorithm we use Z' → bb → μX

- Created 6000 Z* (1.5 TeV) → bb, with at least one muon in final state.
- These b-jets have approximately the energy expected in 4b-jet final state events at CLIC.

Distributions for muons which made it through all layers of detector:

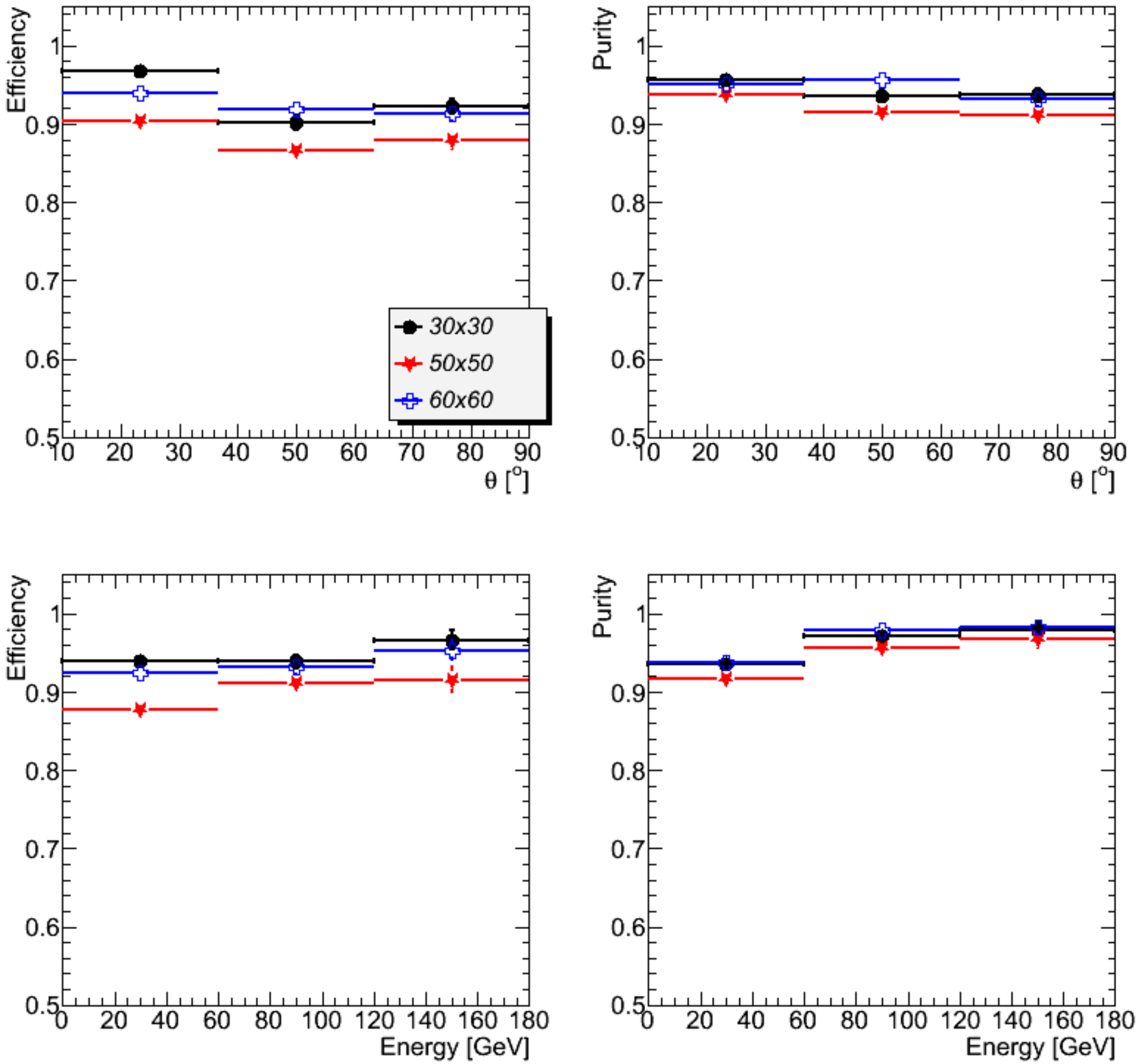
E > 6 GeV in barrel,
E > 4 GeV in endcap.



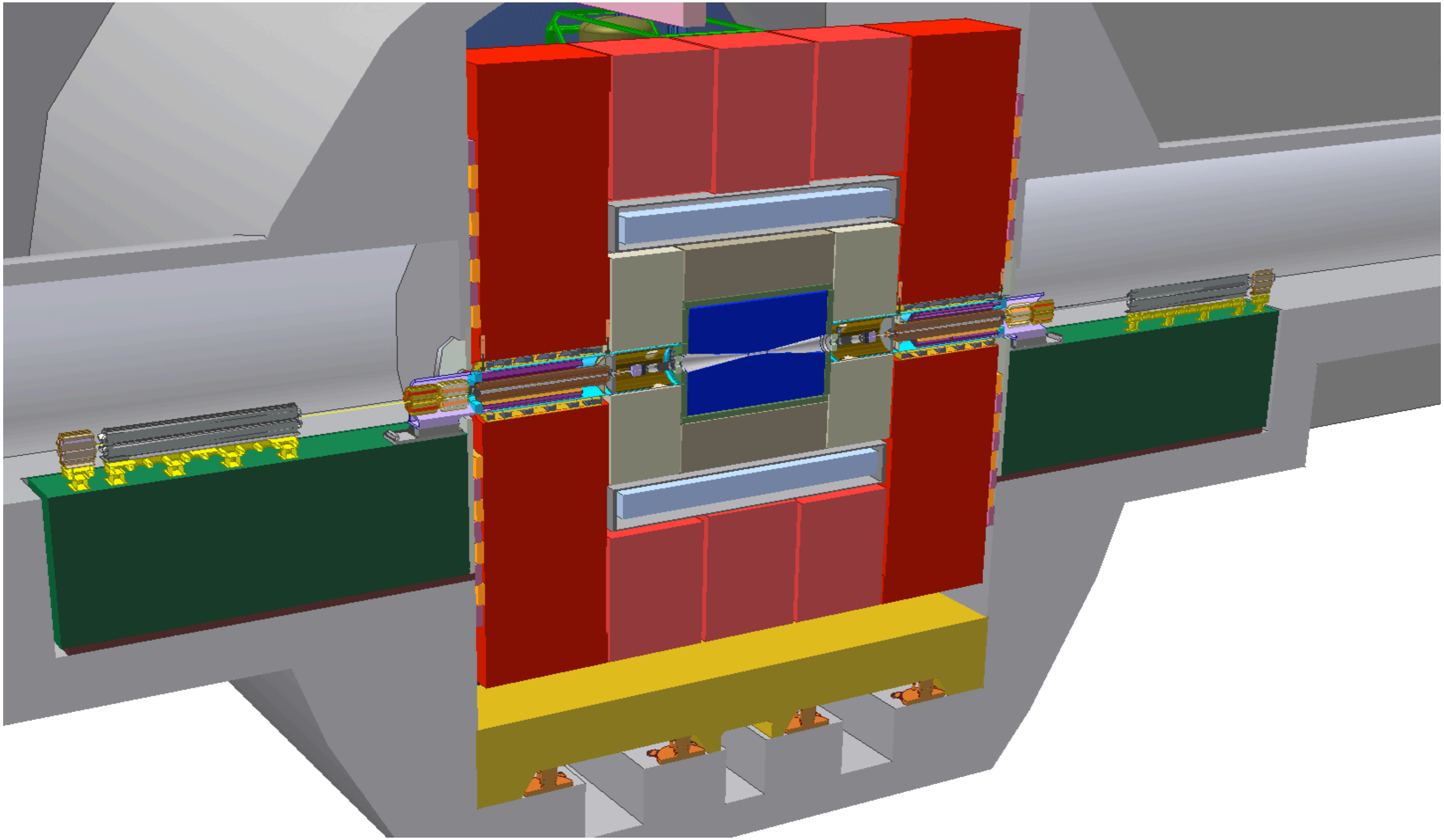
Performance as function of energy and θ

The results for the 50x50 mm^2 cells are worse over the full phase space in E and θ .

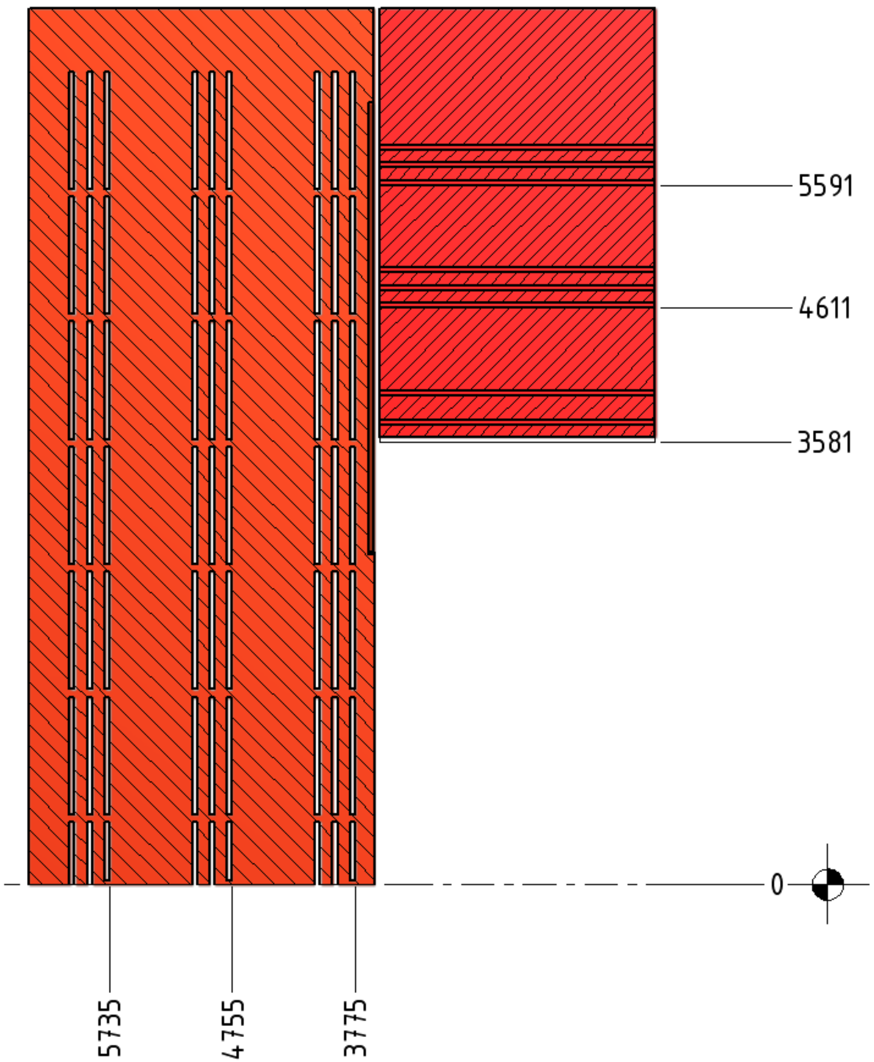
It is unclear why. One reason might be that the algorithm was tuned for 30x30 mm^2, and 60x60 mm^2 is the exact double of that size.



Cut through view of the detector at IP



CLIC detector - full geometry



- For muon ID & pattern recognition
  - 2x three layers beyond tail-catcher

➢ Yoke barrel: 9 sensitive layers
  - Starting with active layer directly after solenoid

➢ Yoke endcap: 10 sensitive layers
  - Including single plug layer

- Granularity: 3 x 3 cm^2 sensor size
- Sensor type: RPC (digital) or scintillators (analog)

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