A CLIC-inspired detector for FCC-ee

FCC-ee Detector Design Meeting - 19.6.2017

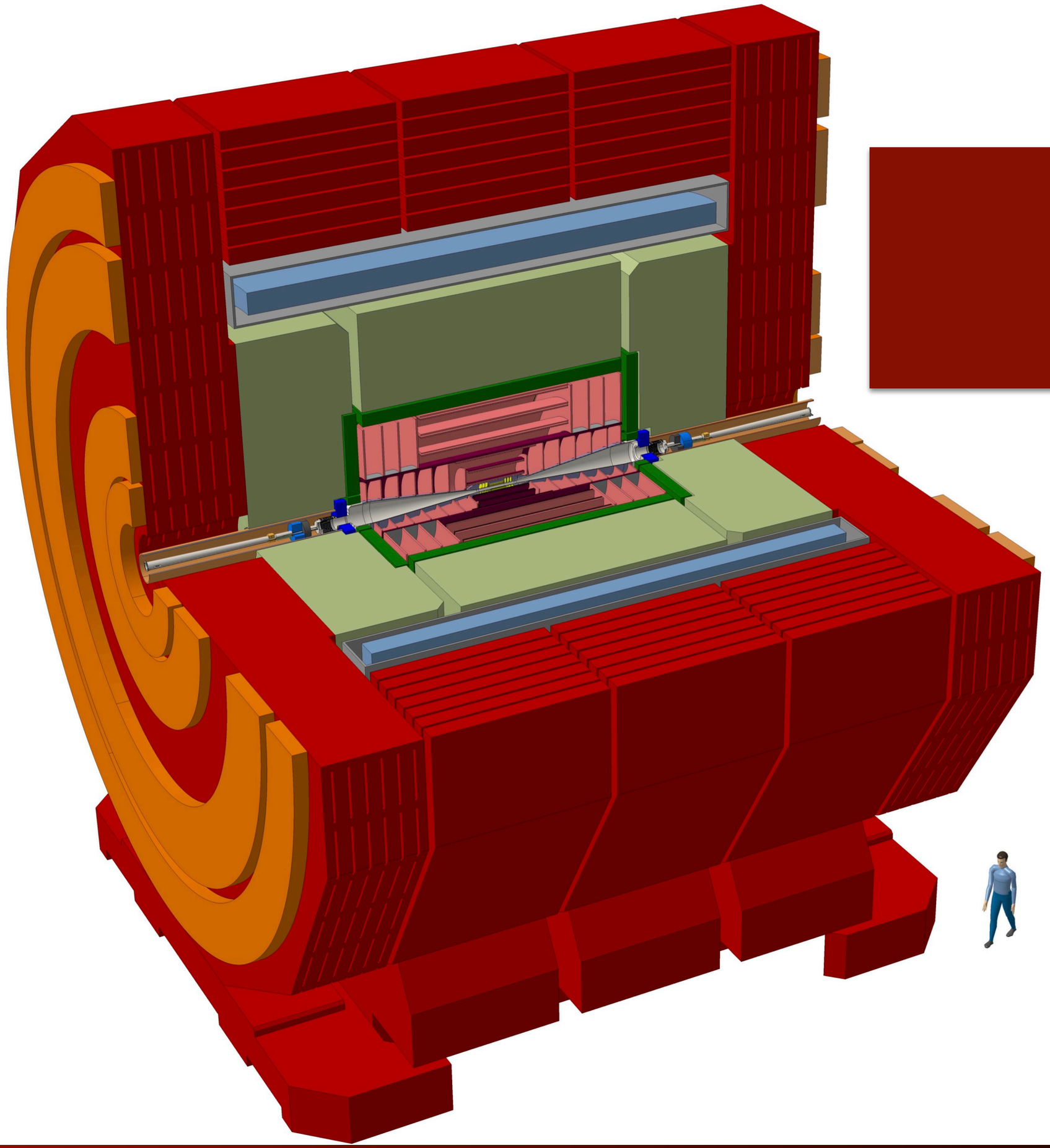
Emilia Leogrande, on behalf of the CERN Linear Collider Detector group (EP-LCD)

Outlook of this talk

- CLIC DETECTOR LAYOUT AND PERFORMANCE
  - Detector requirements
    - from physics
    - from experimental conditions
  - Detector layout
  - Simulation and reconstruction software tools
  - Detector performances

- THE CLIC-INSPIRED DETECTOR FOR FCC-ee
  - Experimental conditions and interaction region
  - Detector layout
    - Vertex
    - Tracker
    - ECal
    - HCal
    - Yoke and muon ID
  - Next steps
  - The CDR Chapter

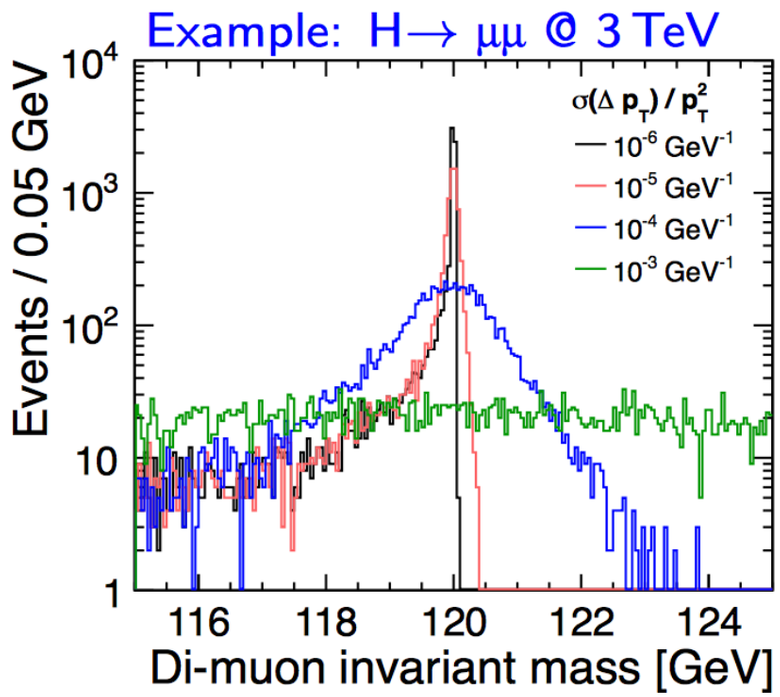
CLIC detector layout and performances



CLIC Detector requirements from physics

- momentum resolution
  - Higgs recoil mass, Higgs coupling to muons, BSM (smuon and neutralino masses)
  - for high p_T tracks

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



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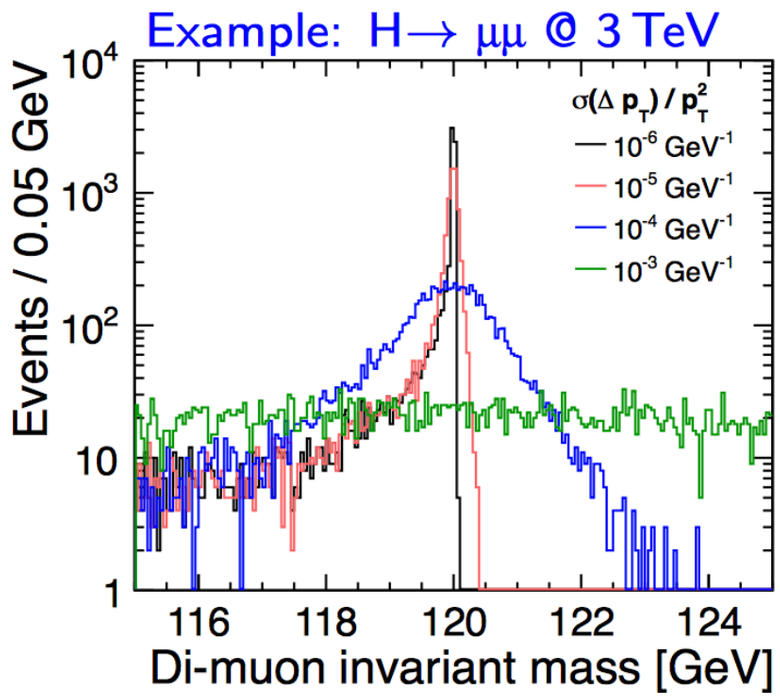
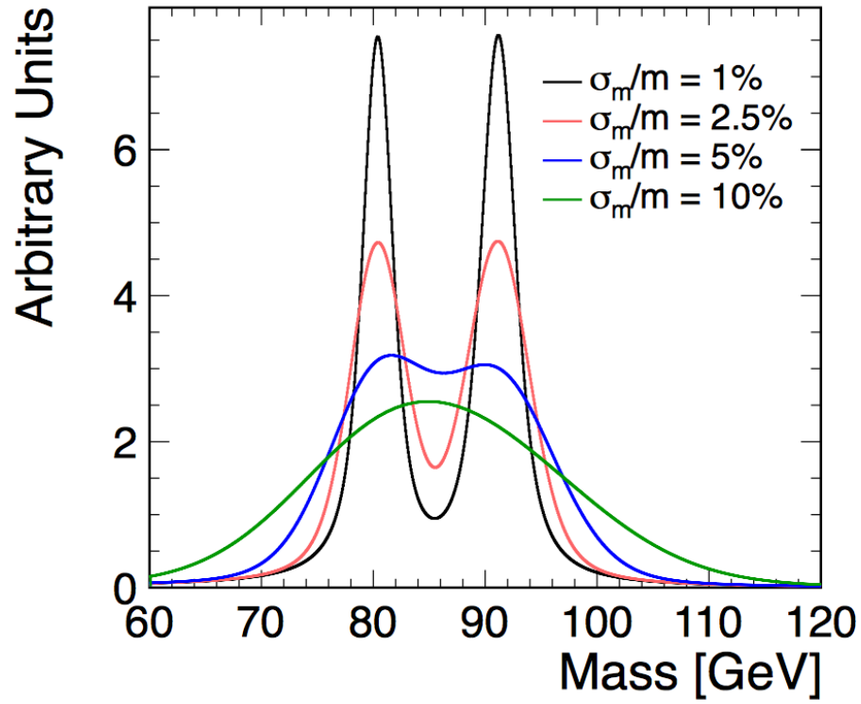


- jet energy resolution
  - W/Z di-jet mass separation
  - jet energy up to 1 TeV

$$\sigma_E/E \simeq 3.5\%$$



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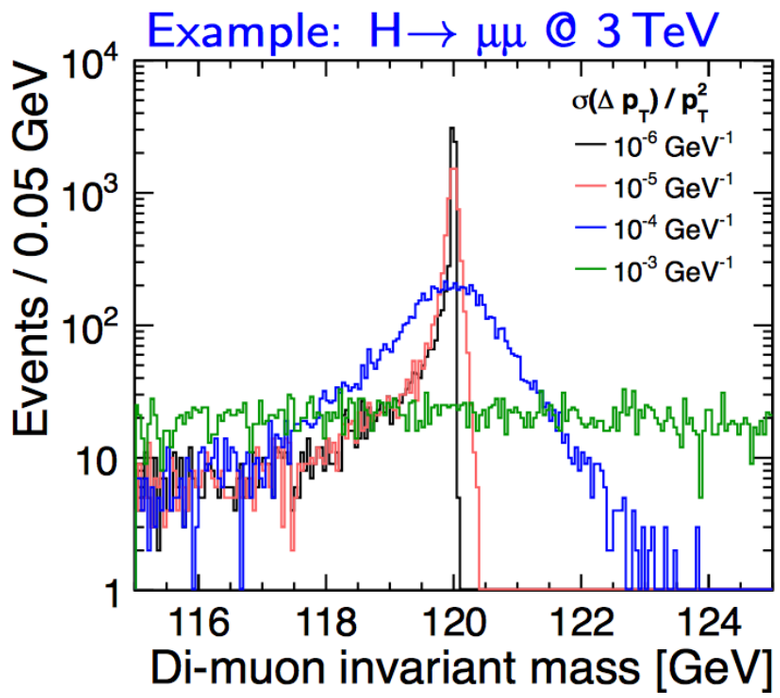

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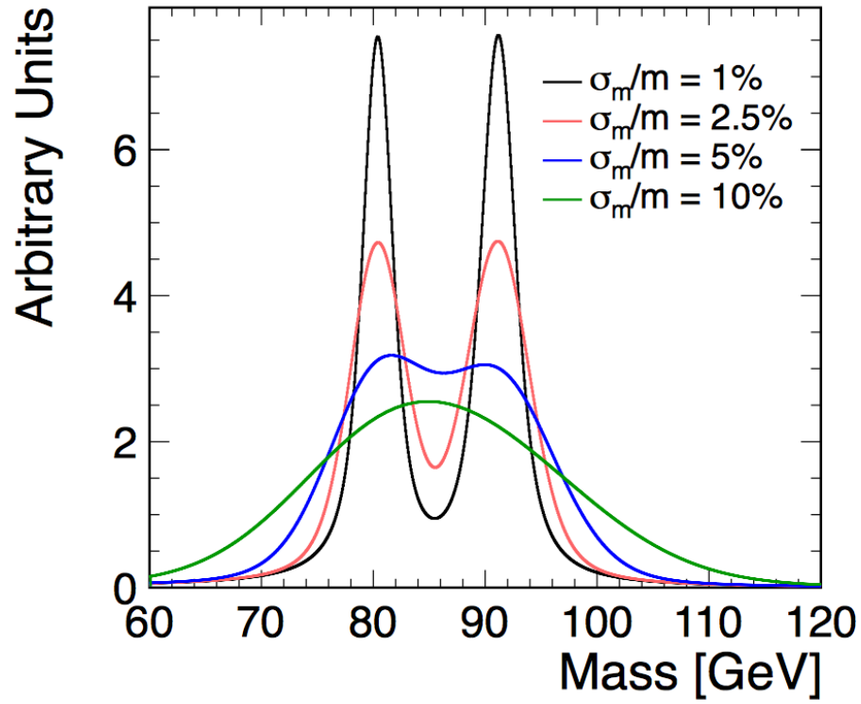

- impact parameter resolution
  - c/b tagging, Higgs BR

$$\sigma_{d_0}^2 = a^2 + \frac{b^2}{p^2 \sin^3\theta}$$

$$a \lesssim 5\mu m \quad b \lesssim 15\mu m GeV$$

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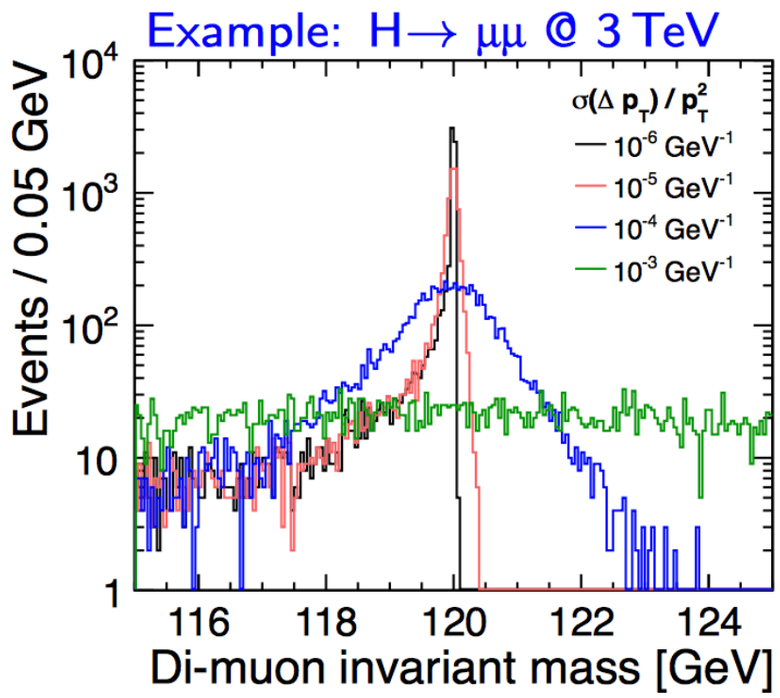

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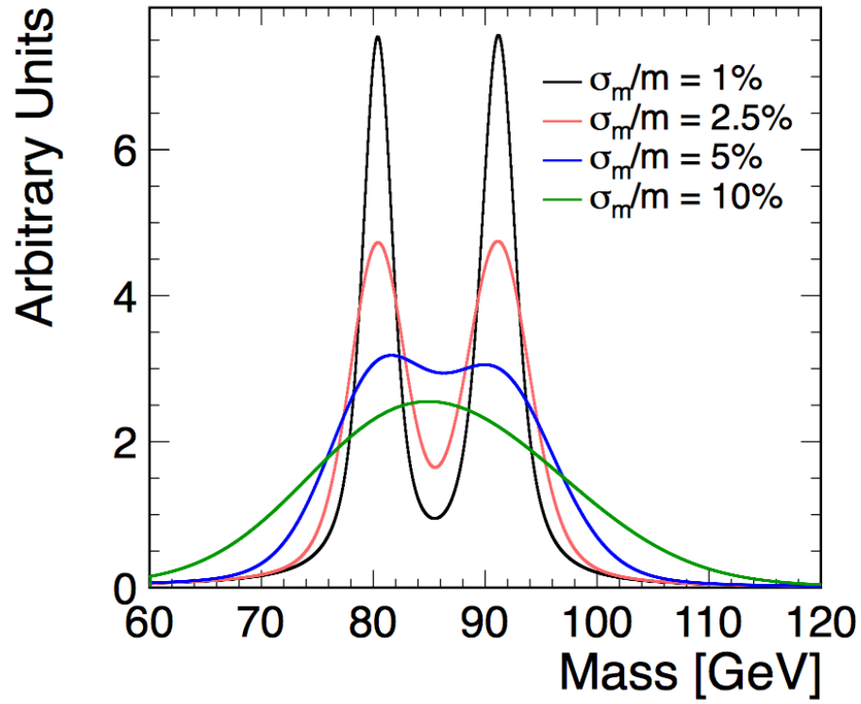

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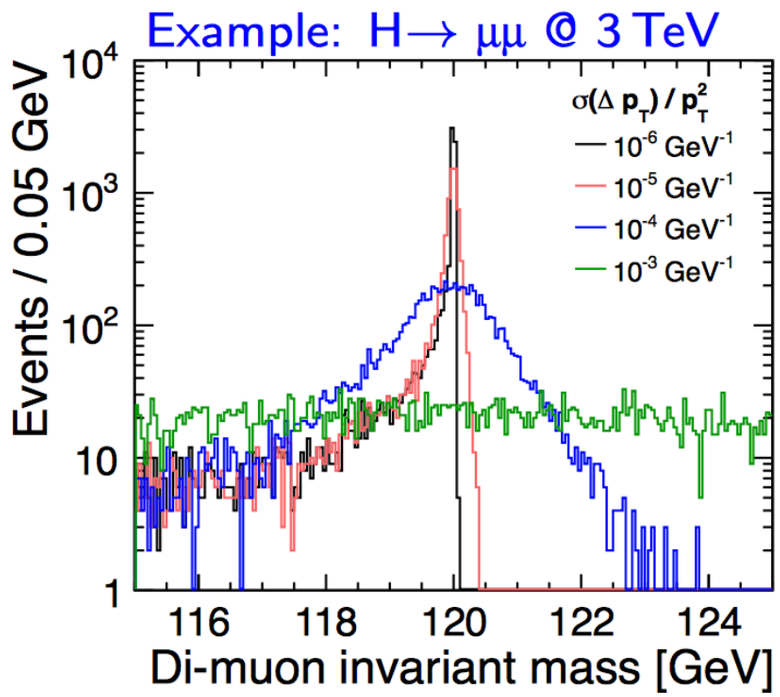

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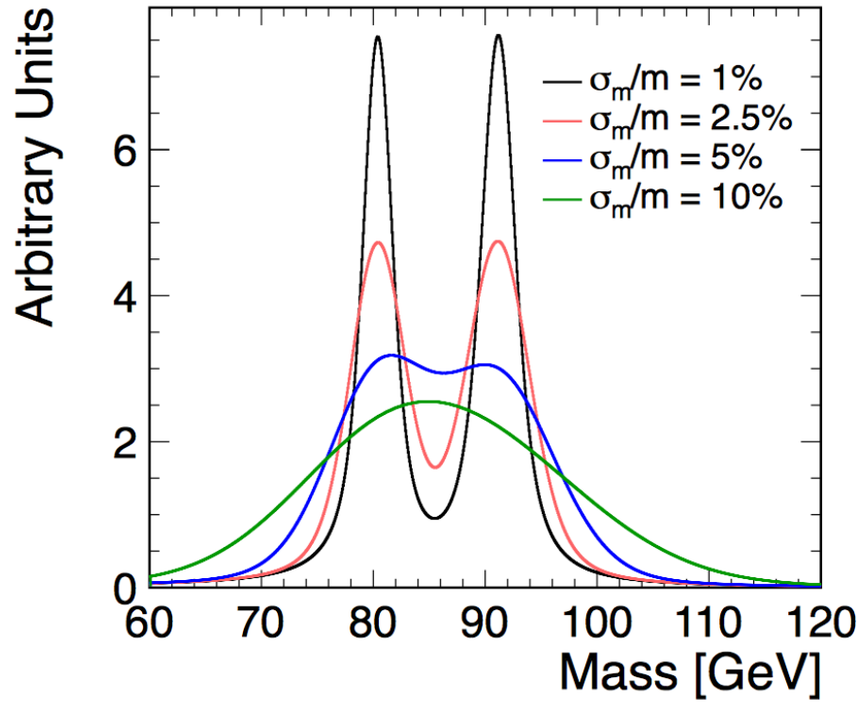

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- lepton ID efficiency > 95 %
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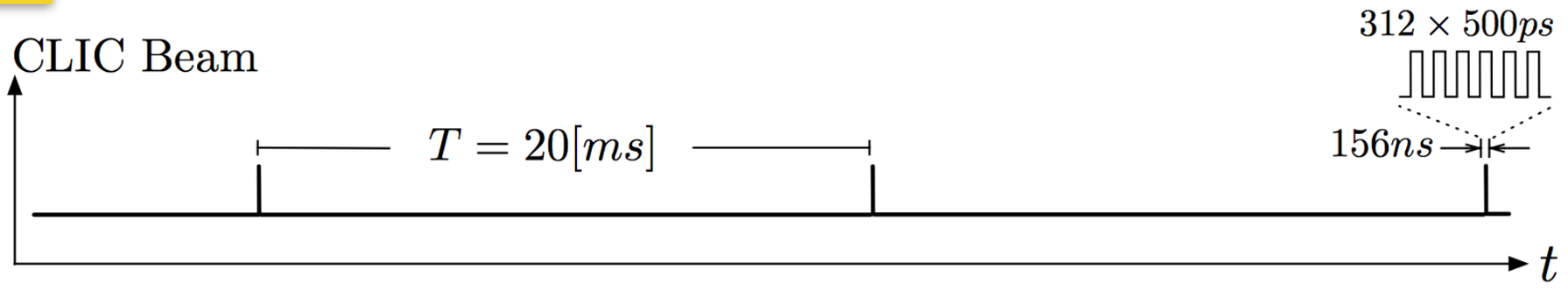
- forward coverage
  - electron and photon tagging (e.g. dark matter studies)

Detector requirements from experimental conditions

BEAM STRUCTURE



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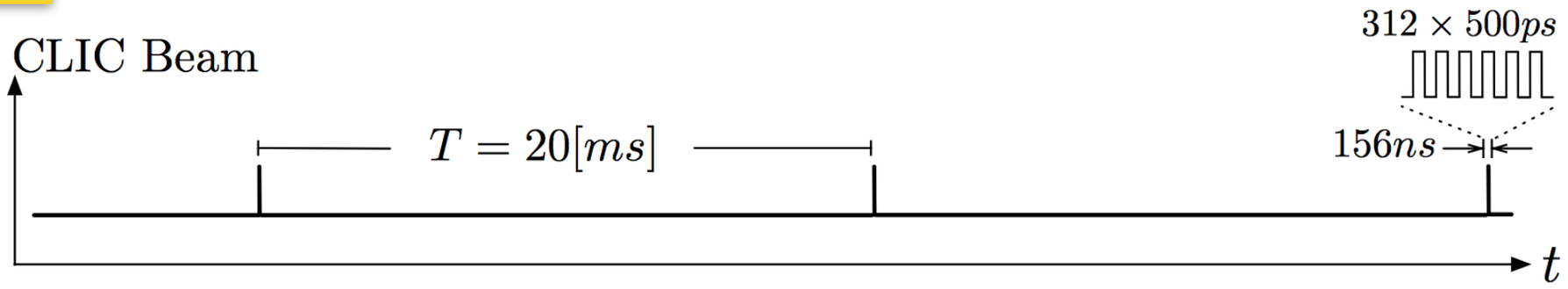

BACKGROUND

Small bunch size =>
strong beamstrahlung

	bunch size
σ_x	45 nm
σ_y	1 nm
σ_z	44 μm

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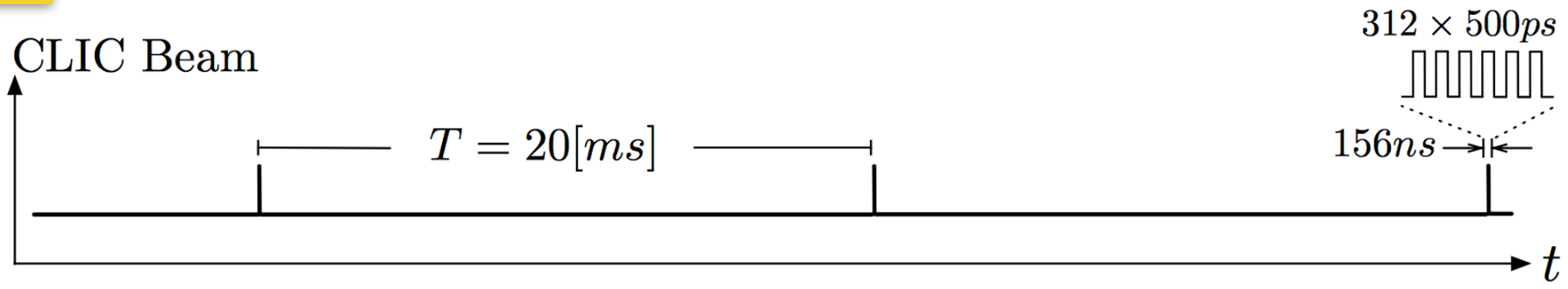

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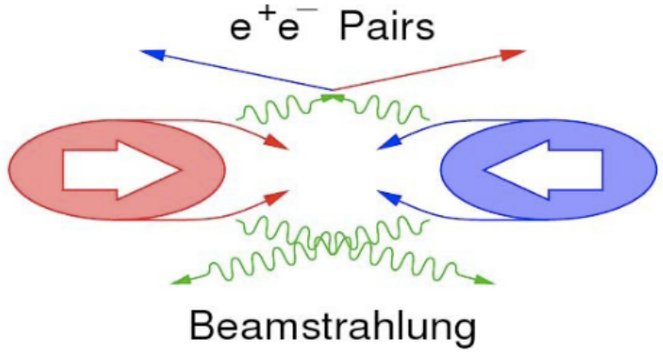

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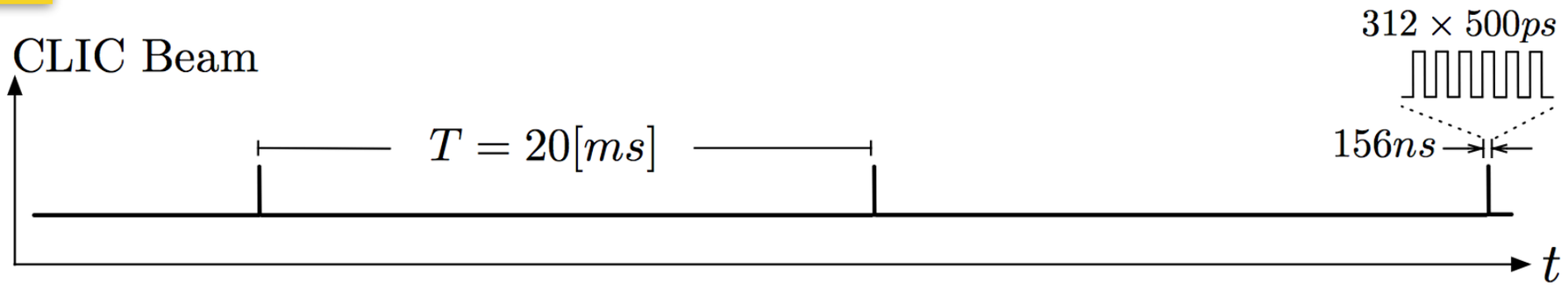

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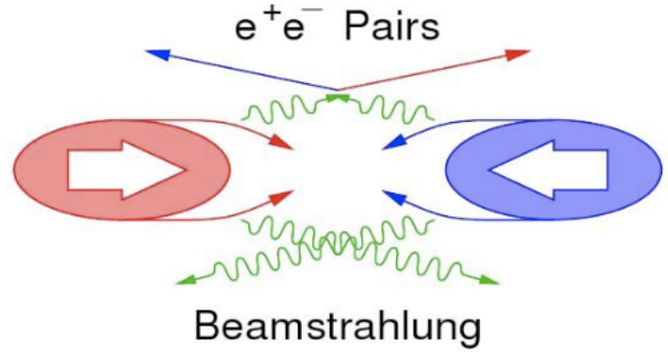

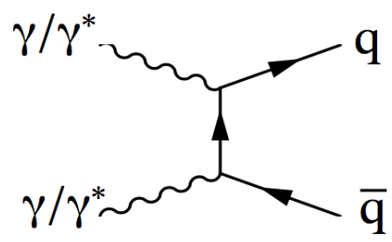

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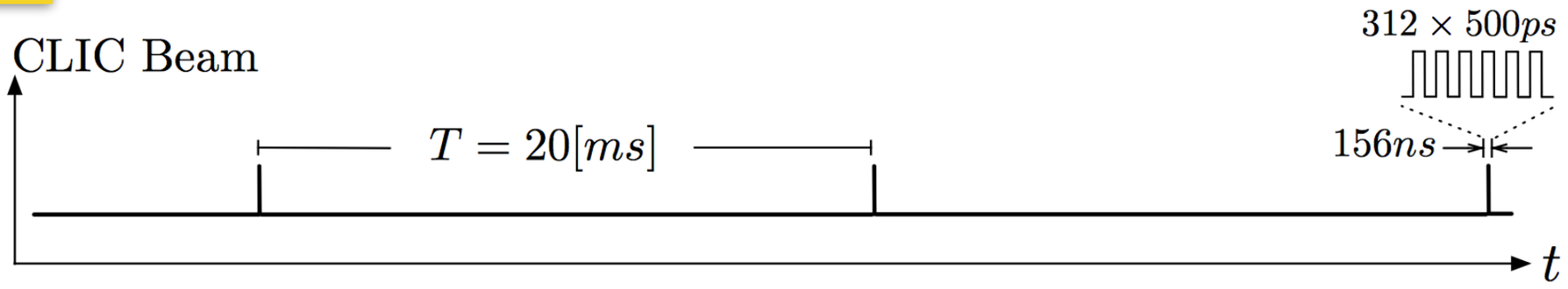

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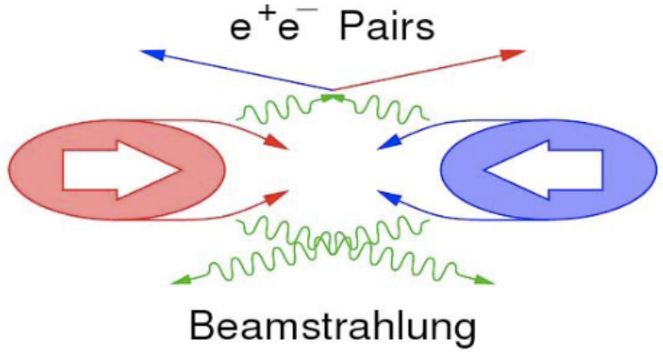

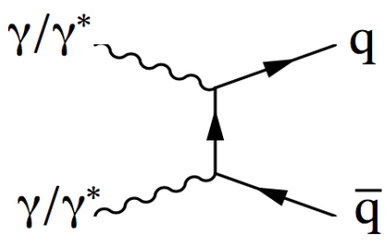

HITS OCCUPANCY: IMPACT ON THE DETECTOR

- Segmentation
  - vertex pixels: 25x25 μm²
  - short strips/pixels in some tracker regions
  - high-granularity calorimeter
- Precise hit timing
  - 10ns hit time stamping in vertex+tracker
  - 1ns accuracy for calorimeter hits

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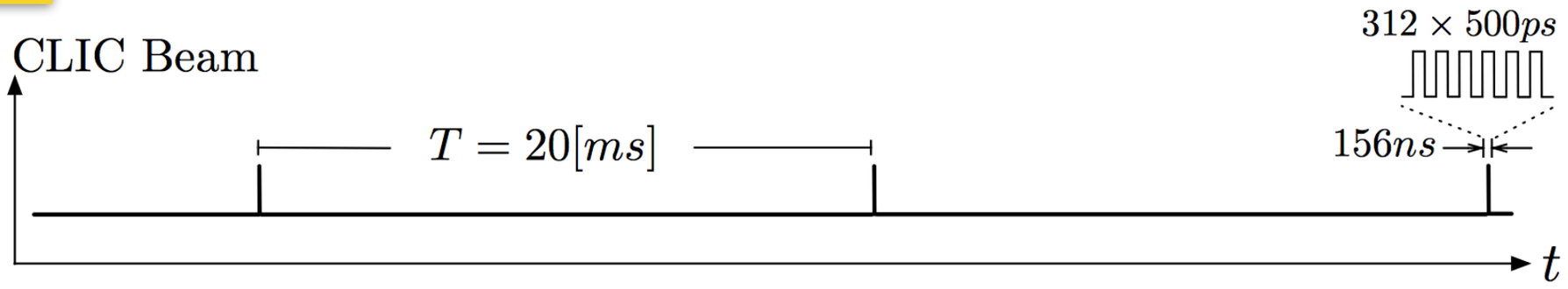

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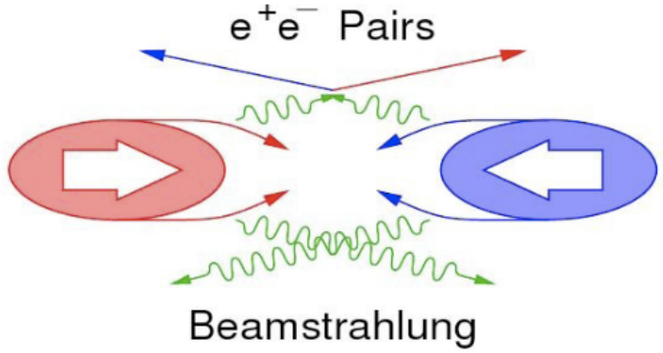

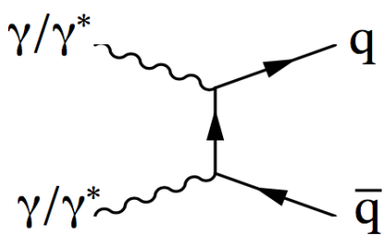

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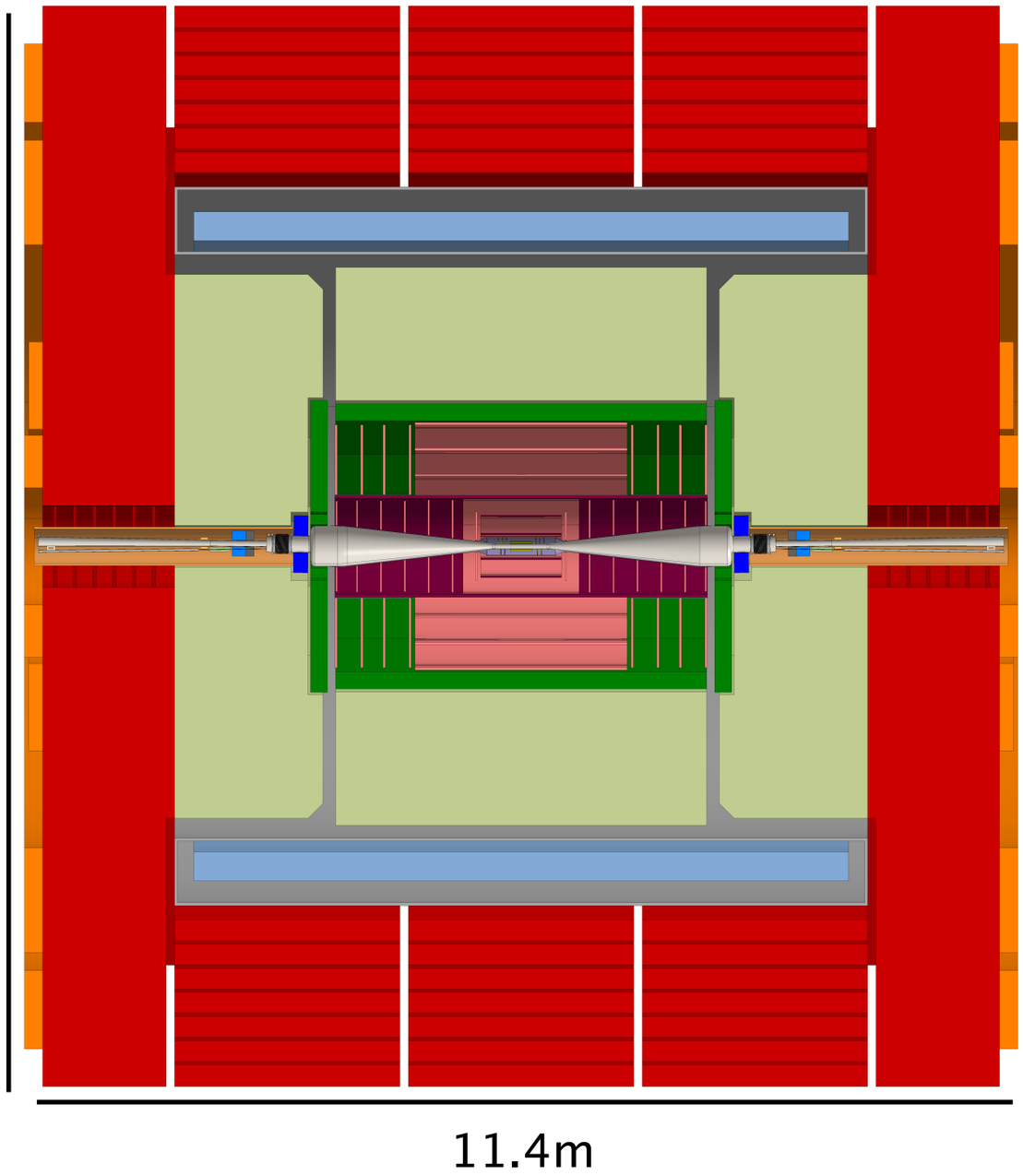
THE PRO OF LOW DUTY CYCLE*

- Cooling realized by air flow (vertex)/water + POWER PULSING
  - allows to reduce material budget in the vertex+tracker
  - allows to have compact calorimeters

*will not be the case for FCC-ee!

CLIC Detector layout



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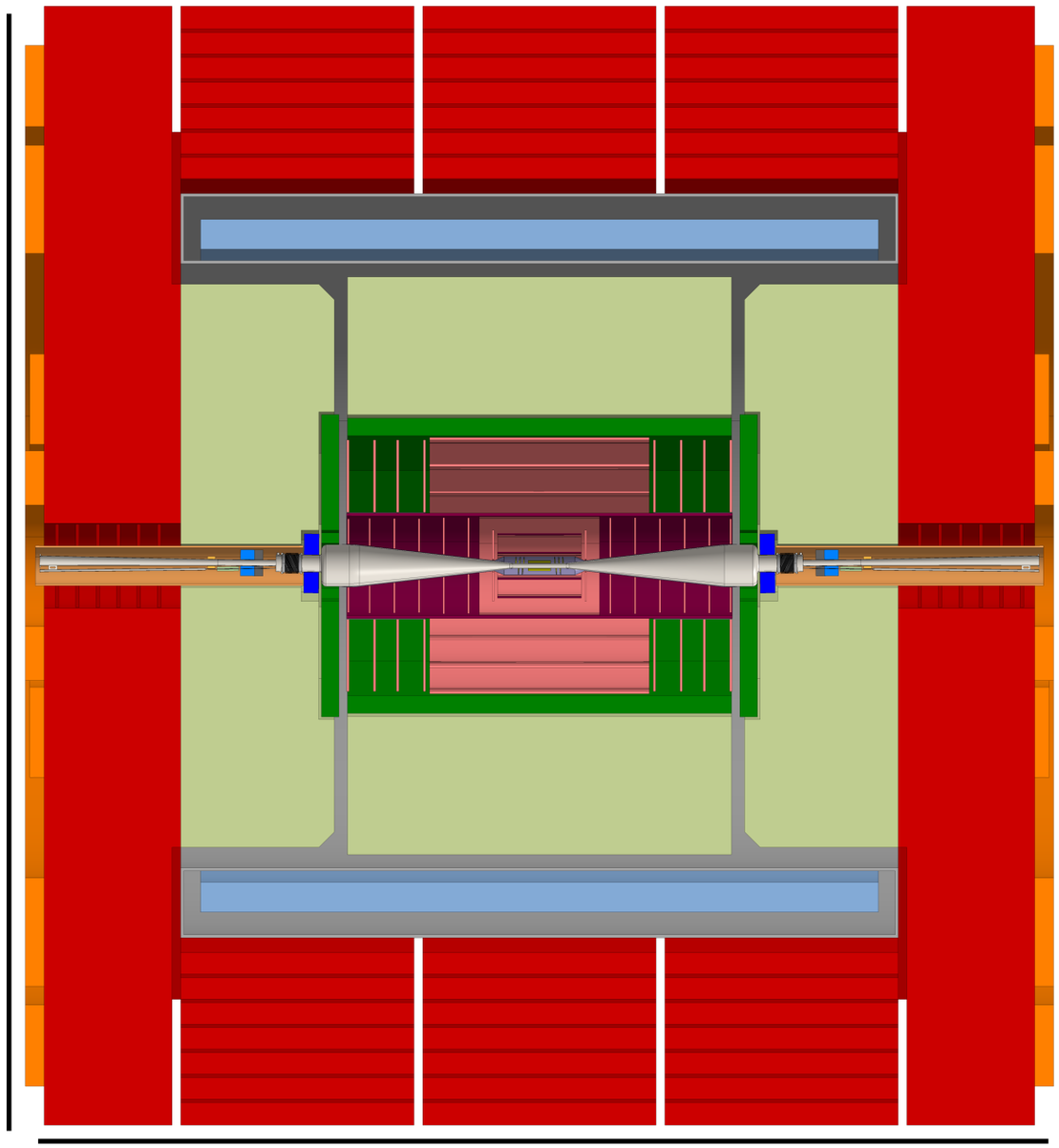
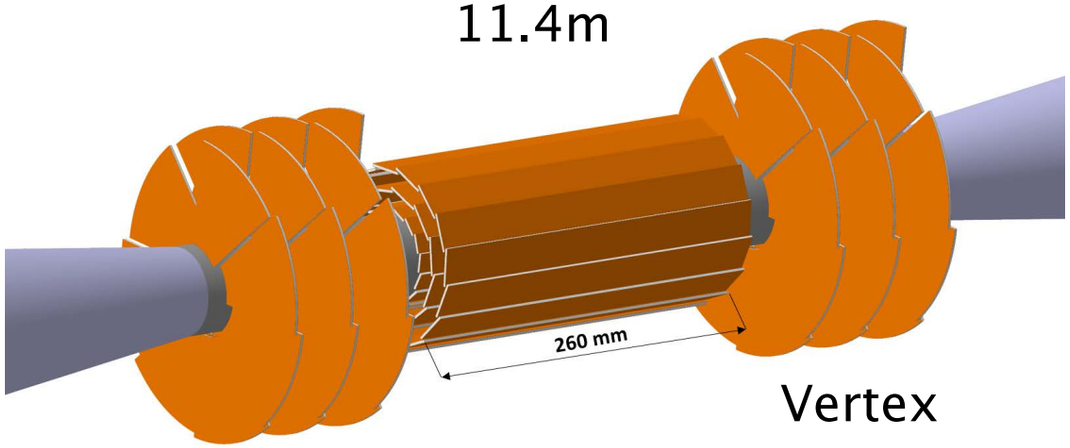
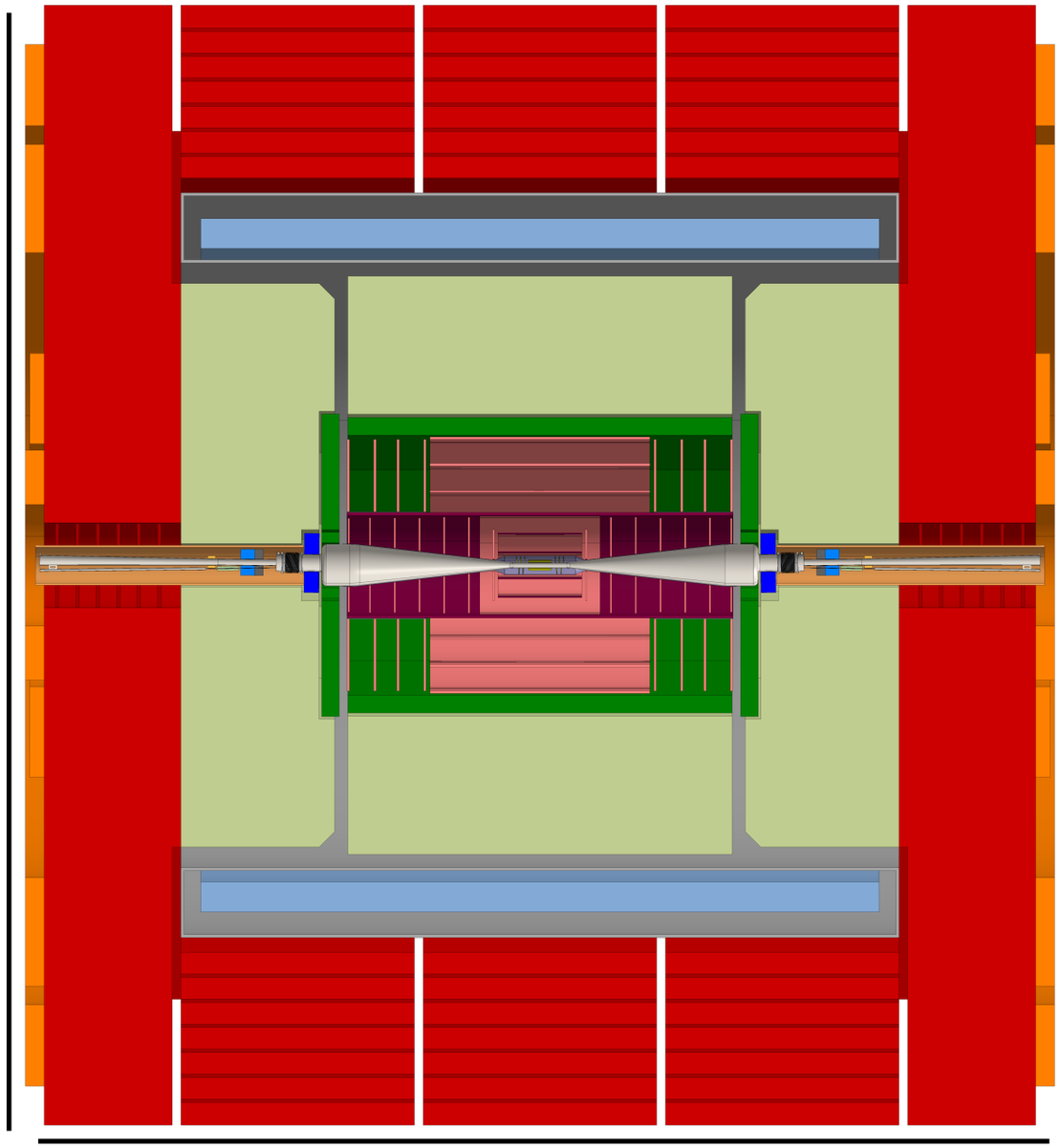
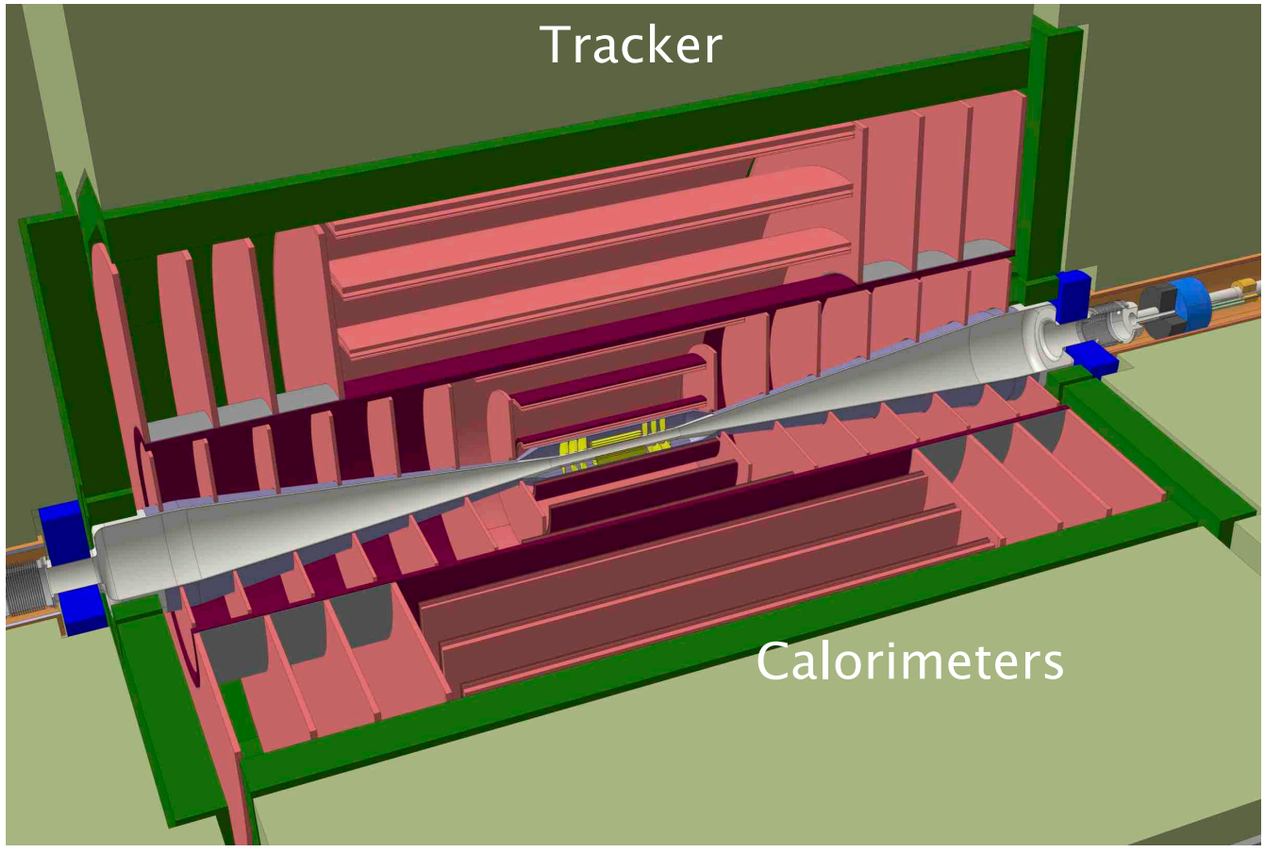


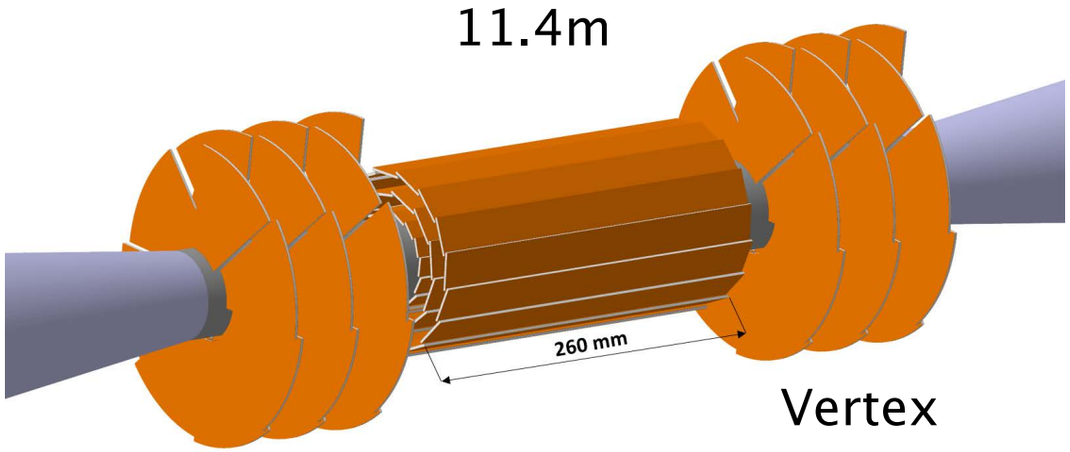


Vertex

CLIC Detector layout







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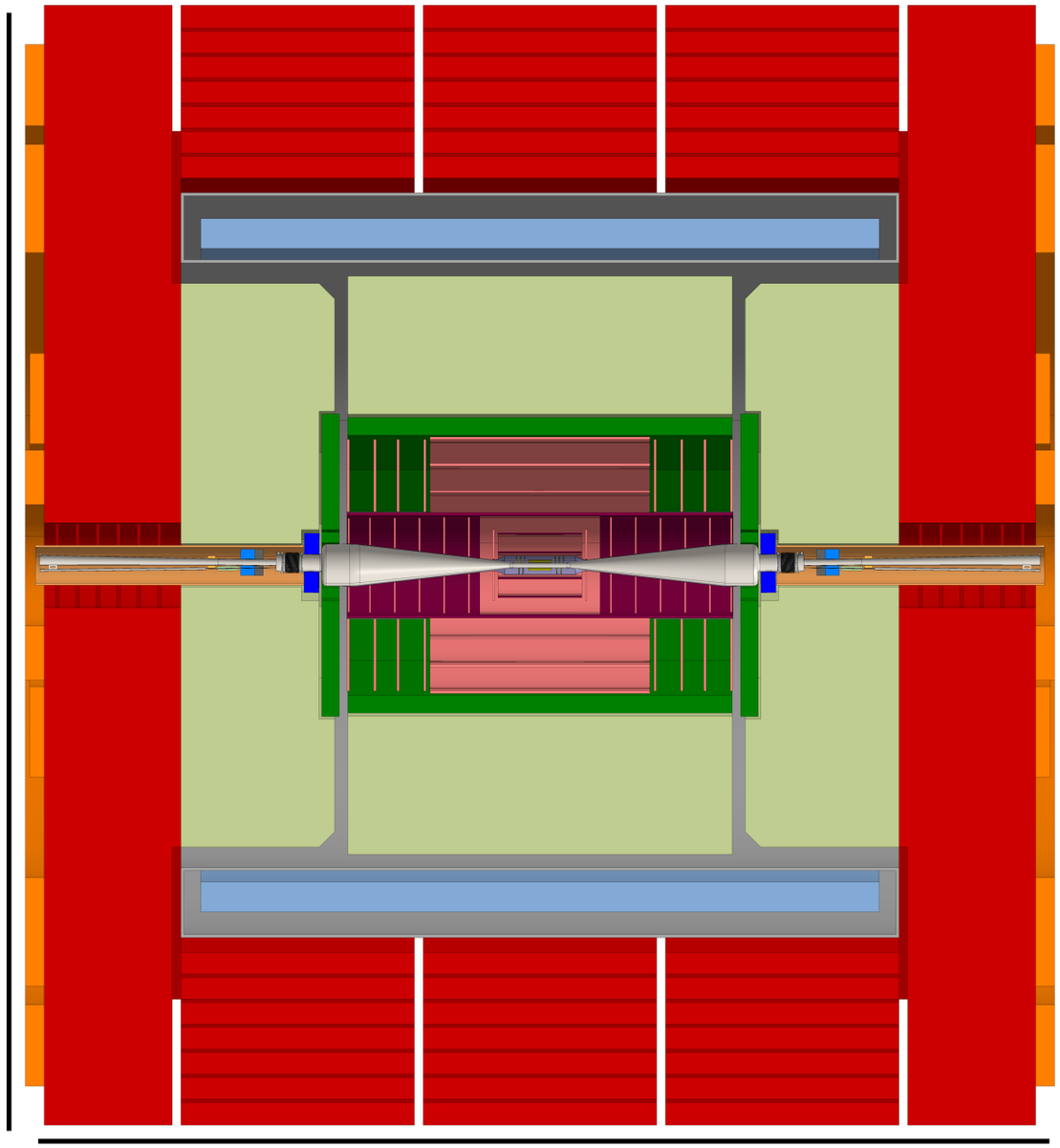

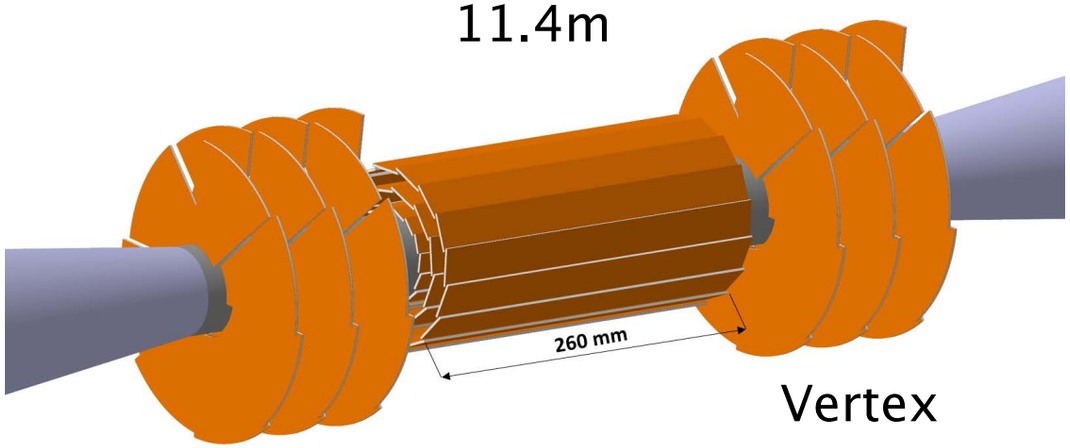

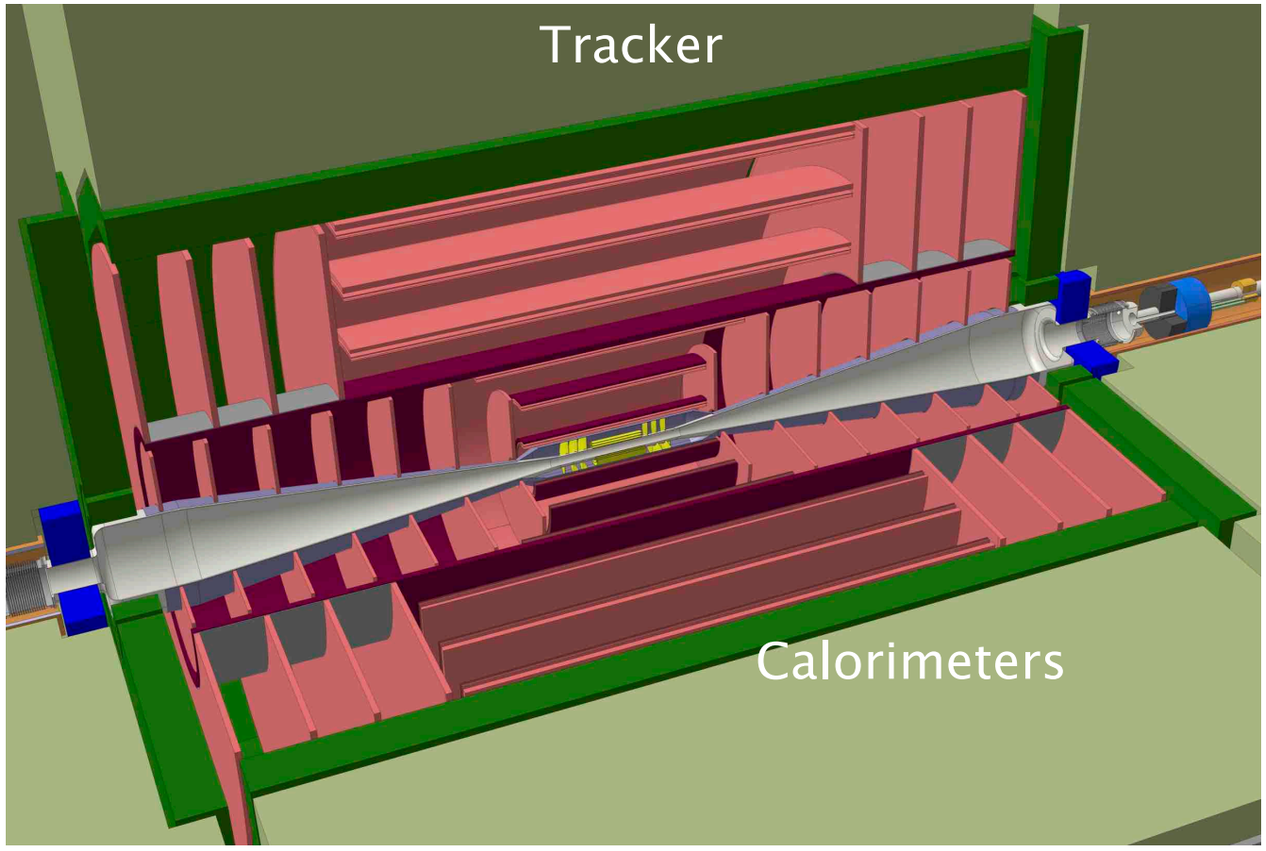

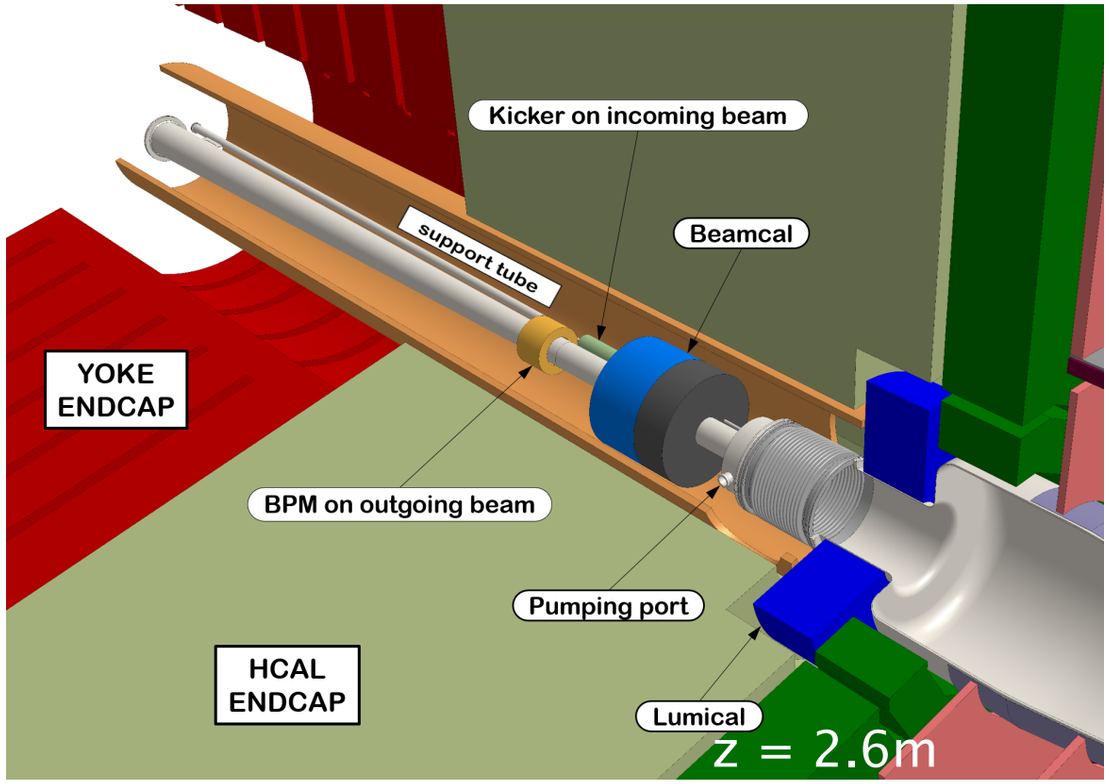

Simulation and reconstruction software tools

- DD4Hep is the single source of geometry information for simulation, reconstruction and analysis
  - DetElements [C++ drivers which interpret XML files with detector parameters]
    - =>for simulation
  - DDRec DataStructures [reconstruction interfaces filled by C++ drivers]
  - DD4Hep Surfaces [position of hits, local-to-global coordinate transformation, average material]
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https://indico.cern.ch/event/505613/contributions/2230854/attachments/1347096/2046776/Oral-472_sailer_RecoWDD4hep.pdf

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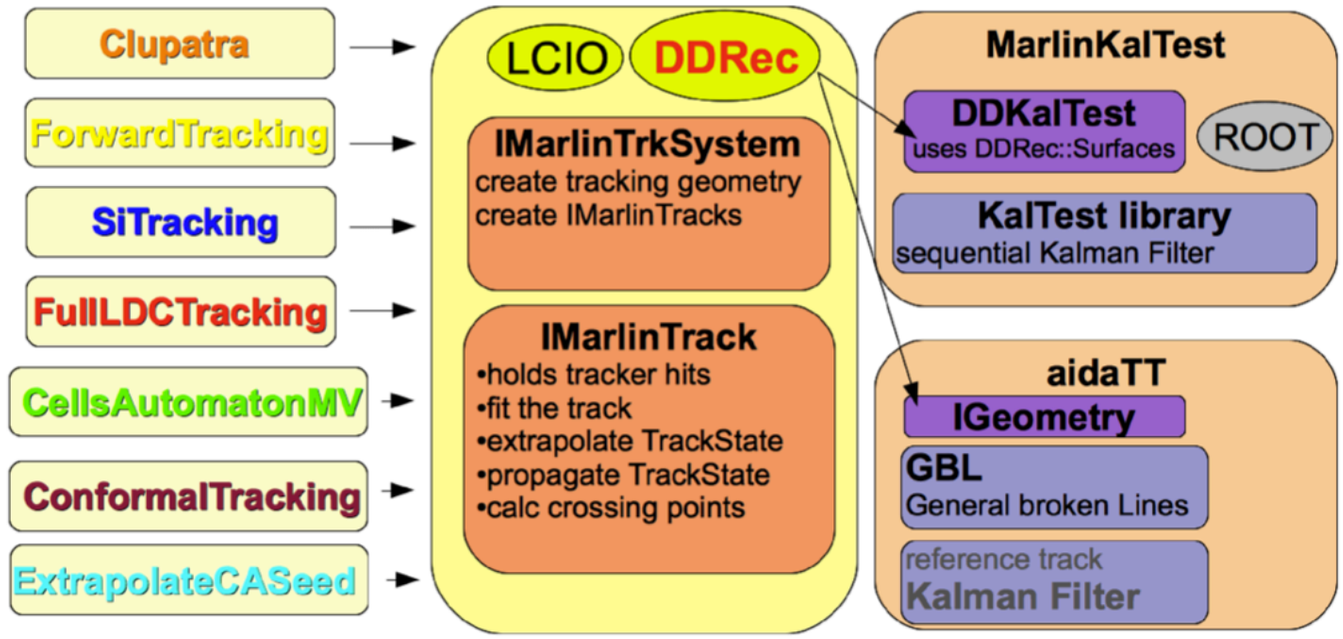
Geometry interface to the track reconstruction

- Pattern recognition/track finding algorithms
- Track fitting (`DDKalTest`, `aidaTT`)



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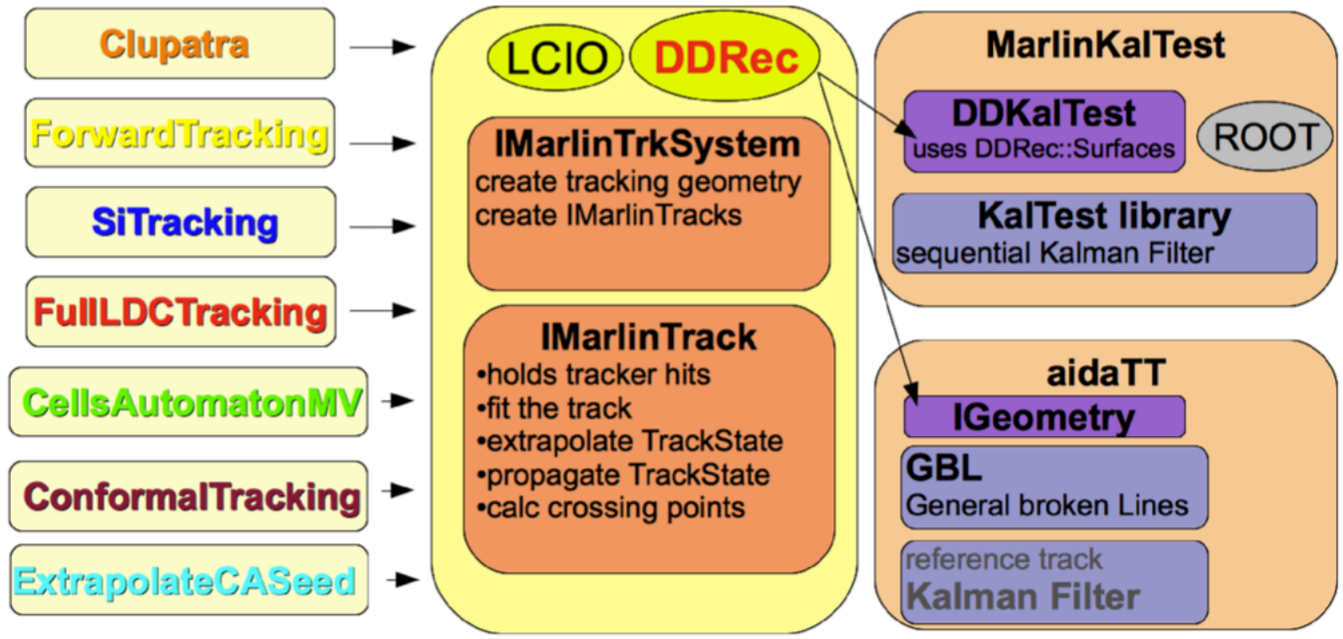

- DDMarlinPandora glues DD4Hep, the Linear Collider Framework (Marlin), and PandoraPFA
  - DDRec DataStructures
  - tracks
  - calorimeter hits

- PandoraPFA [pattern recognition algorithm in high-granularity calorimeters]

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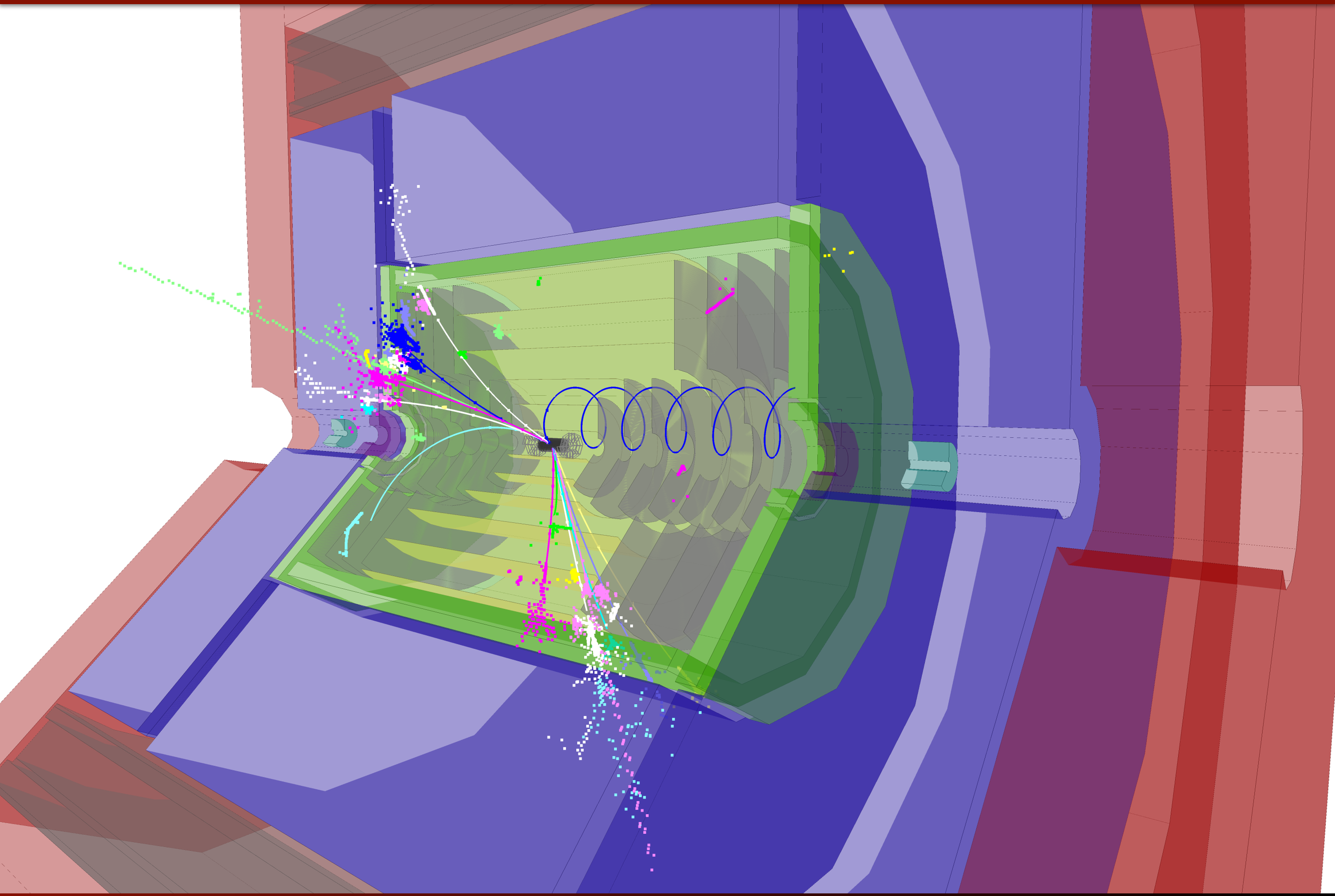
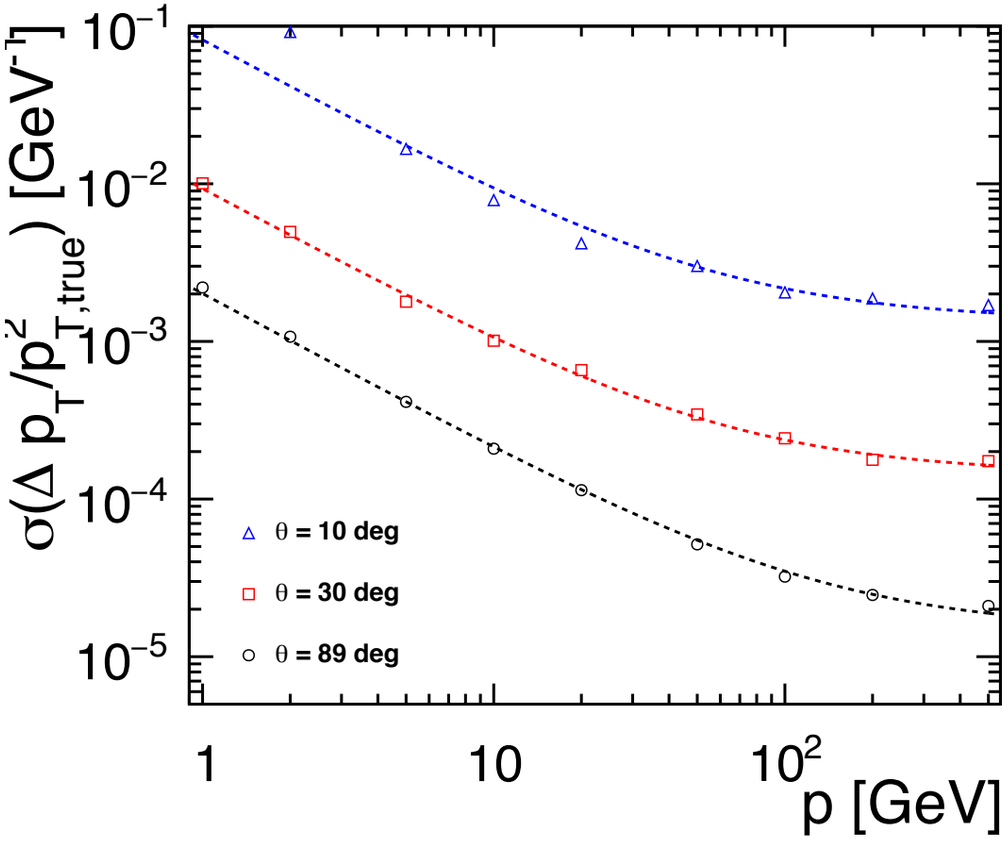


Detector performance examples

Momentum resolution

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

reached for high energy muons in the central region



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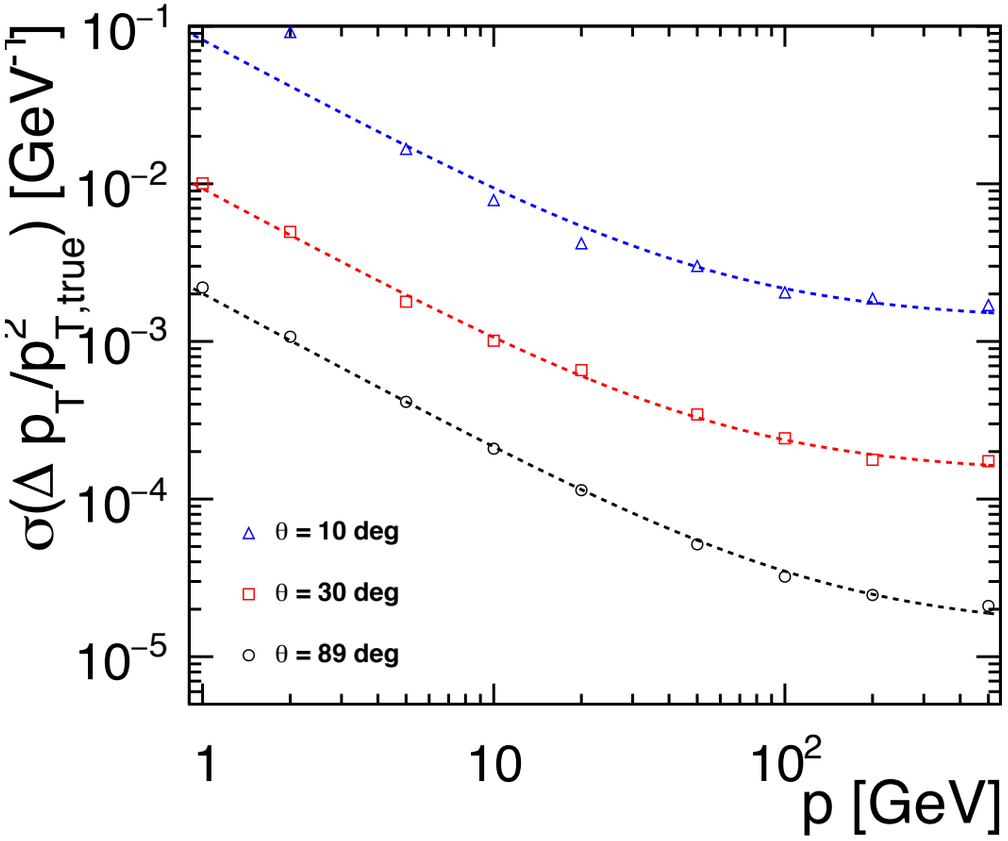
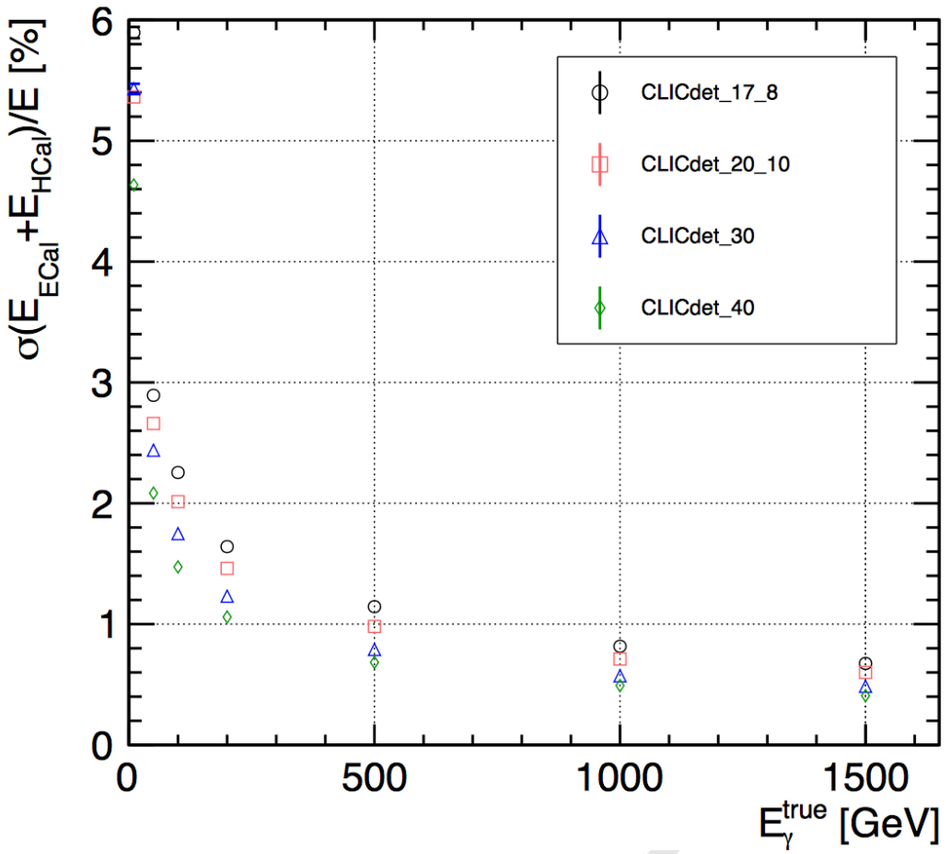




Photon energy resolution

$$\sigma_E/E \simeq 1.5\%$$

reached for 100 GeV photons with the current detector model (CLICdet_40)

Experimental conditions and layout for the FCC-ee CLIC-like detector

- ☆ Requirements from physics

  See talk by M. Dams @FCCWeek

- ☆ Requirements from experimental conditions
  —> following slides

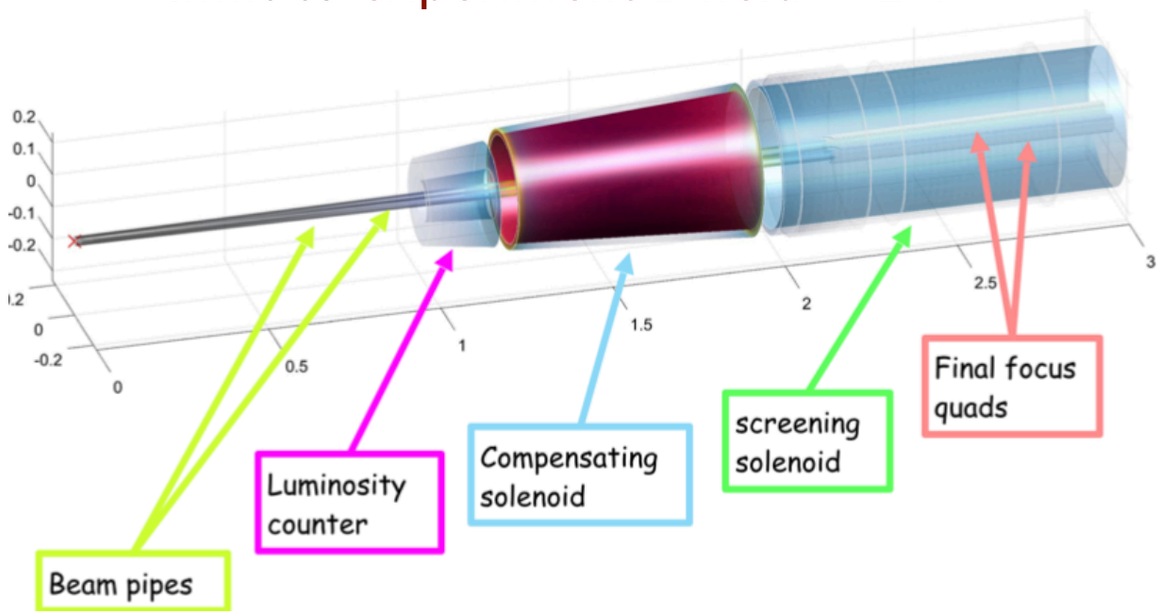
Experimental conditions

energy/beam [GeV]	45	120	175
bunches/beam	70760	770	78
Bunch spacing [ns]	3.0	400	4000

- ☆ Large number of bunches —> crossing angle 30mrad to avoid parasitic collisions

- ☆ Last focusing quadrupole close to IP (L*=2.2m)
- ☆ Compensating solenoid to prevent emittance blow-up due to non-zero crossing angle

=>limit to experiment B field = 2 T



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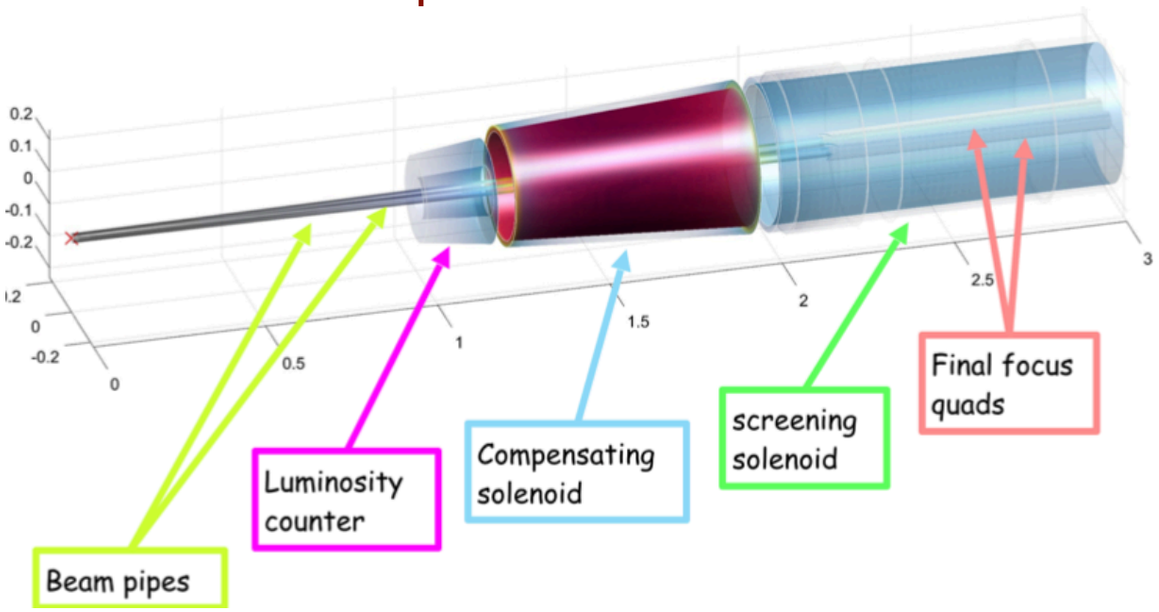
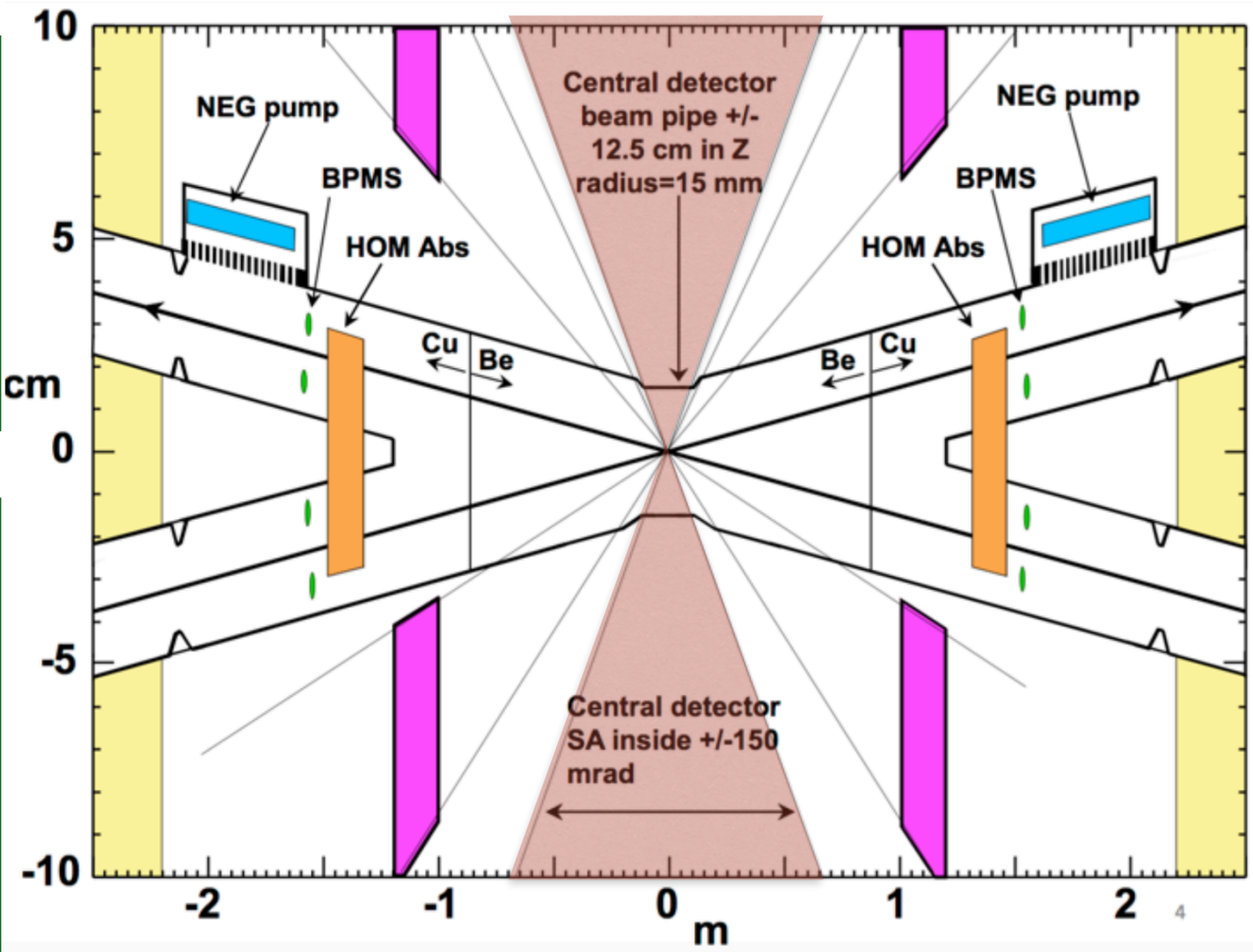




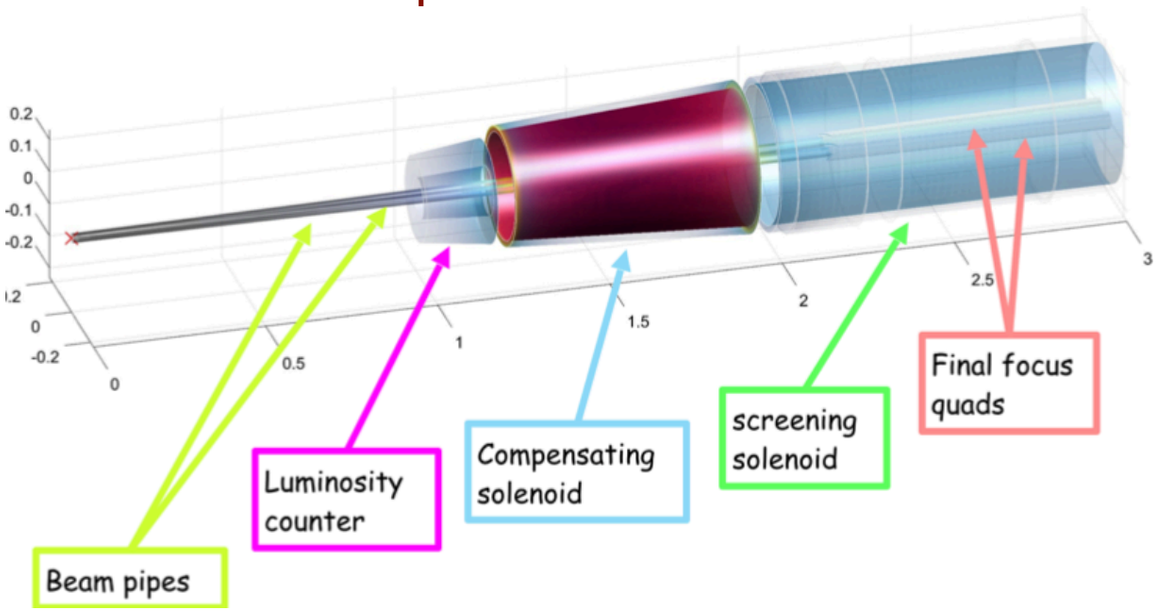
Experimental conditions – Interaction region

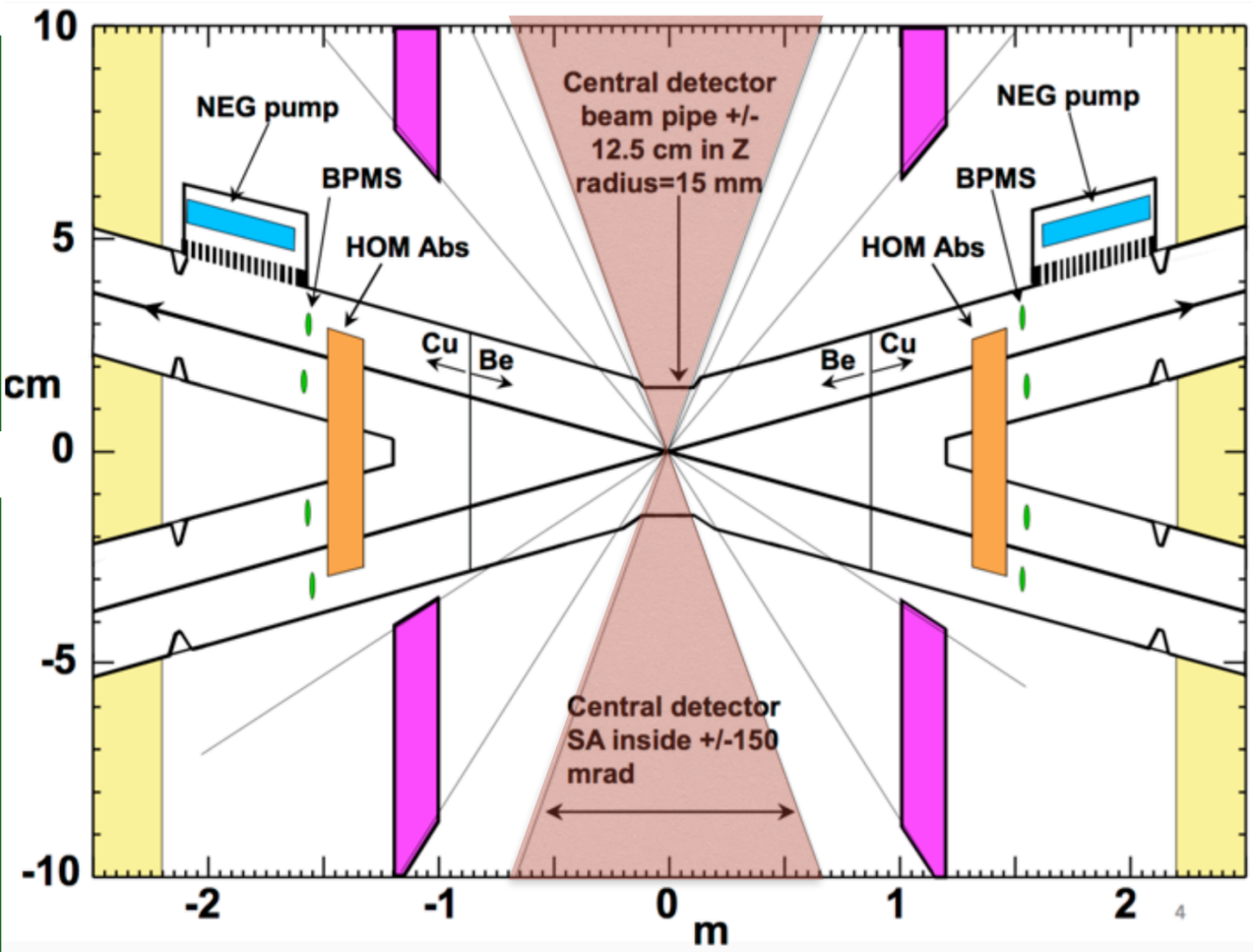
energy/beam [GeV]	45	120	175
bunches/beam	70760	770	78
Bunch spacing [ns]	3.0	400	4000

- ☆ Large number of bunches —> crossing angle 30mrad to avoid parasitic collisions

- ☆ Last focusing quadrupole close to IP (L*=2.2m)
- ☆ Compensating solenoid to prevent emittance blow-up due to non-zero crossing angle

=>limit to experiment B field = 2 T

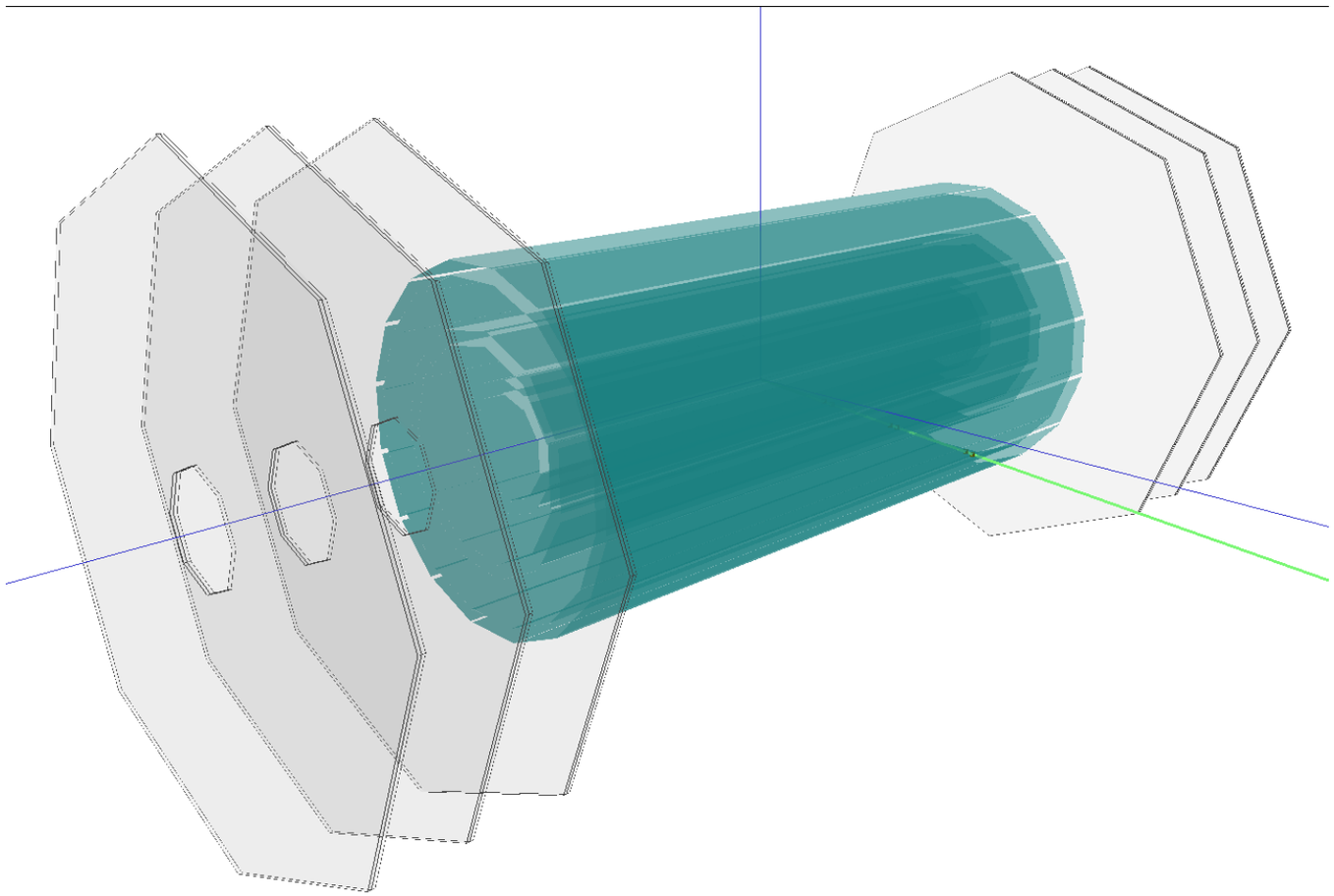




- ☆ Beam-beam background per BX
  - ☆ e^+e^- pairs
  - ☆ $\gamma\gamma$->hadrons
- ☆ Synchrotron radiation

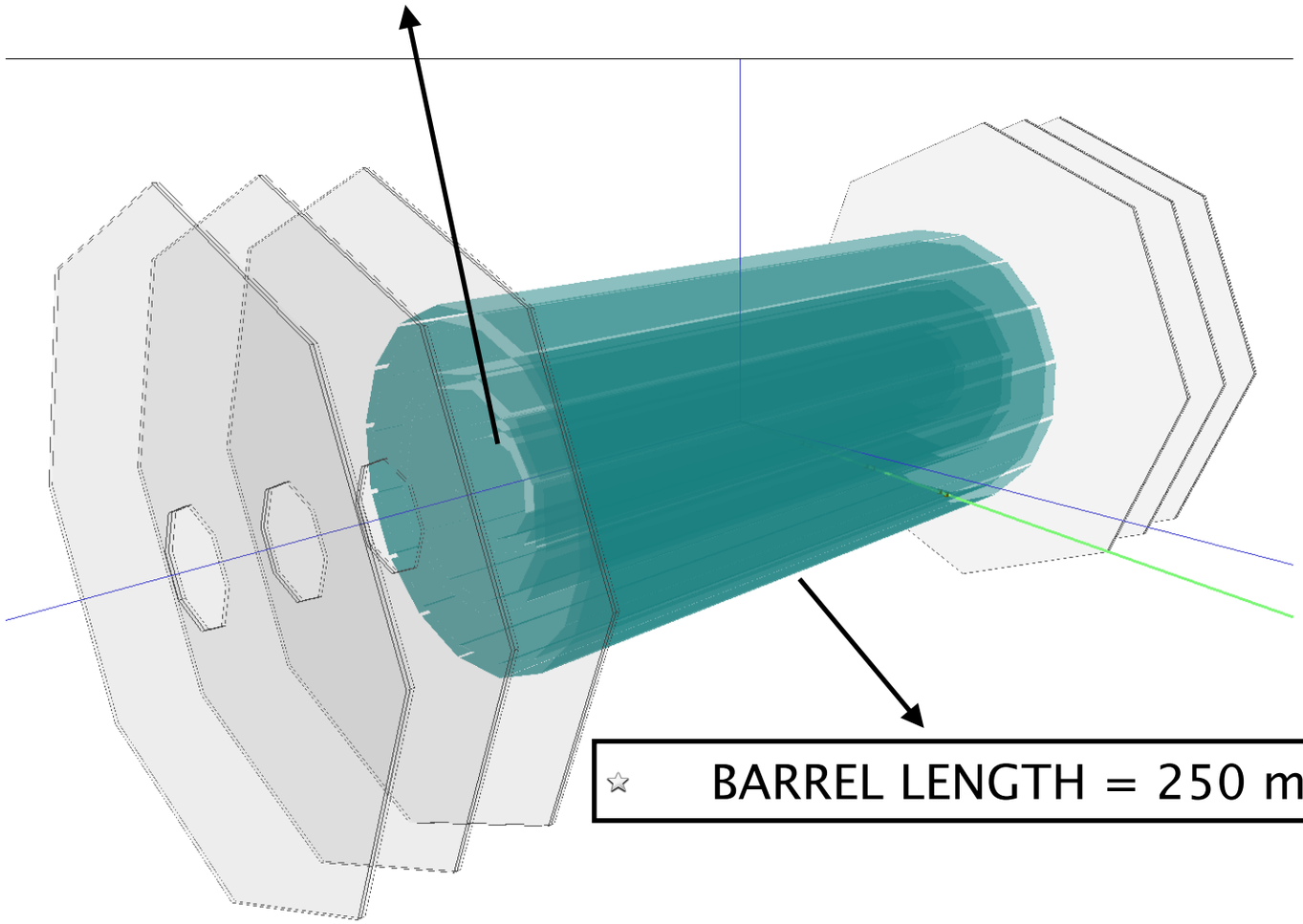
See talk by G. Voutsinas @FCCWeek

Detector layout/ Vertex



Detector layout/ Vertex

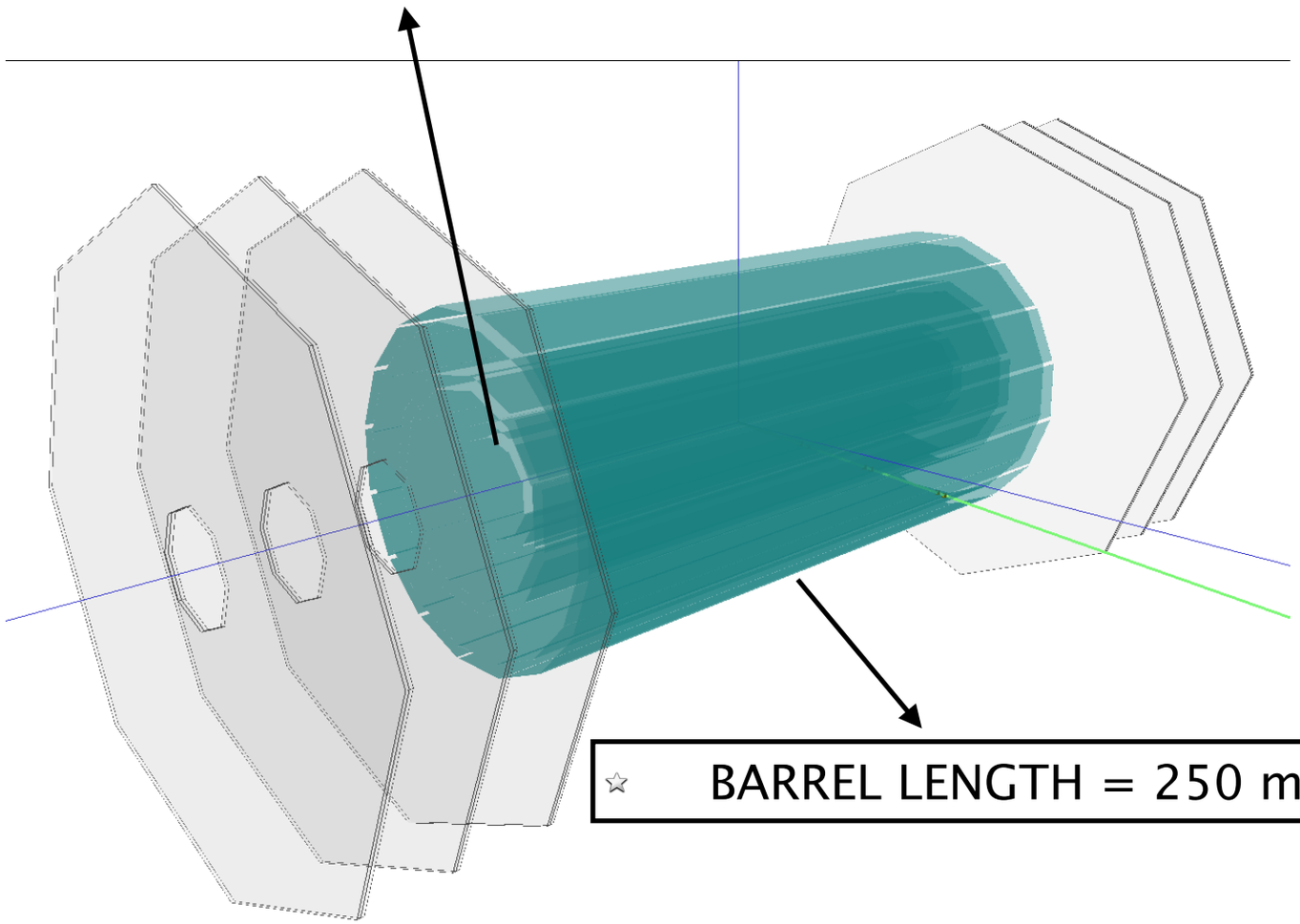
- INNER LAYER closer to the beam pipe
  - depends on beam-induced background



- BARREL LENGTH = 250 mm

Detector layout/ Vertex

- ☆ INNER LAYER closer to the beam pipe
  - ☆ depends on beam-induced background



- ☆ BARREL LENGTH = 250 mm

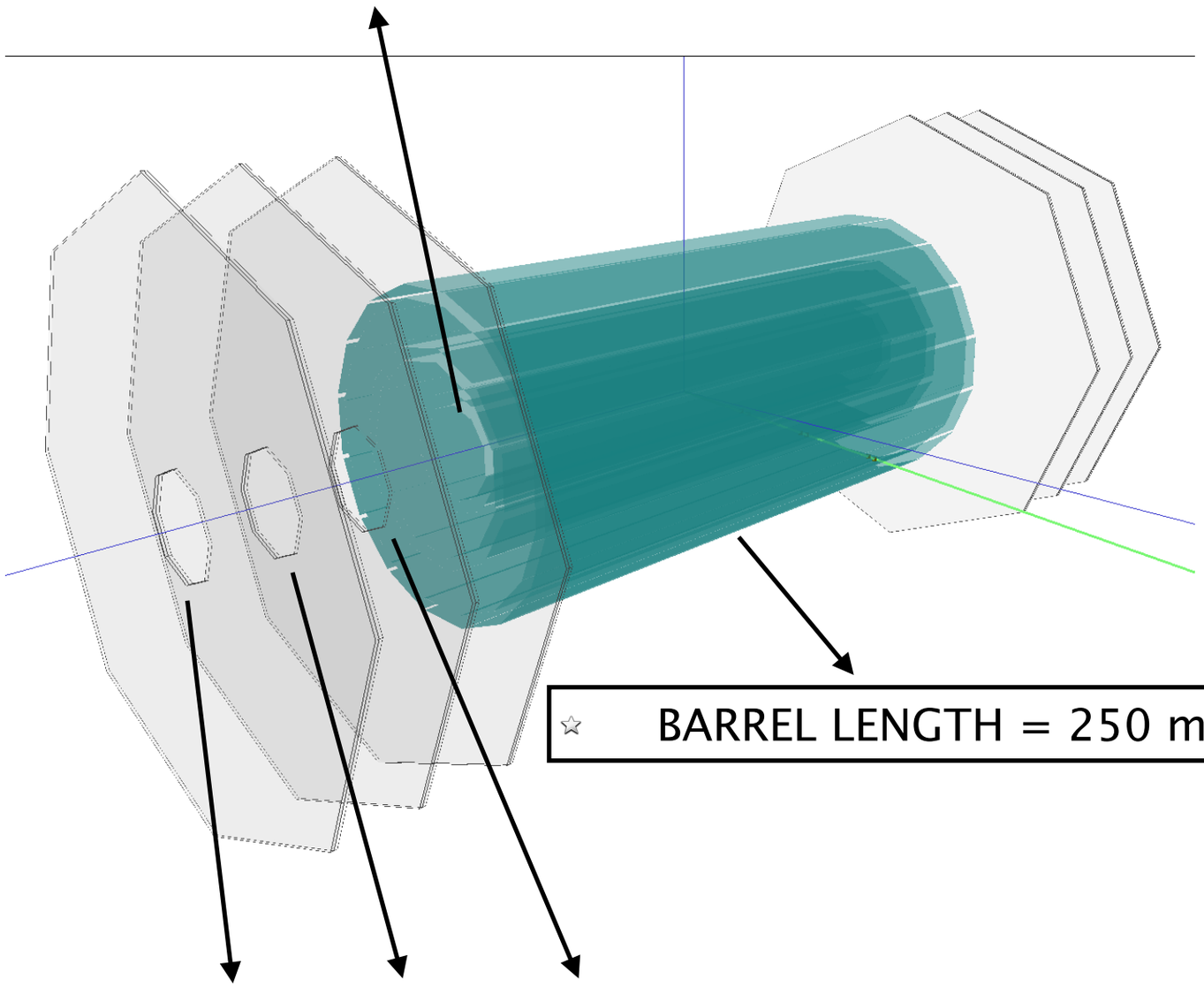
Scale all the barrel layers*

double layer radius [mm]	CLIC	FCC
1st	31-33	17-19
2nd	44-46	37-39
3rd	58-60	57-59

*layer thickness may need to be increased to accommodate water cooling

Detector layout/ Vertex

- ☆ INNER LAYER closer to the beam pipe
  - ☆ depends on beam-induced background



- ☆ BARREL LENGTH = 250 mm

- ☆ DISKS INNER RADIUS closer to the beam pipe

Scale all the barrel layers*

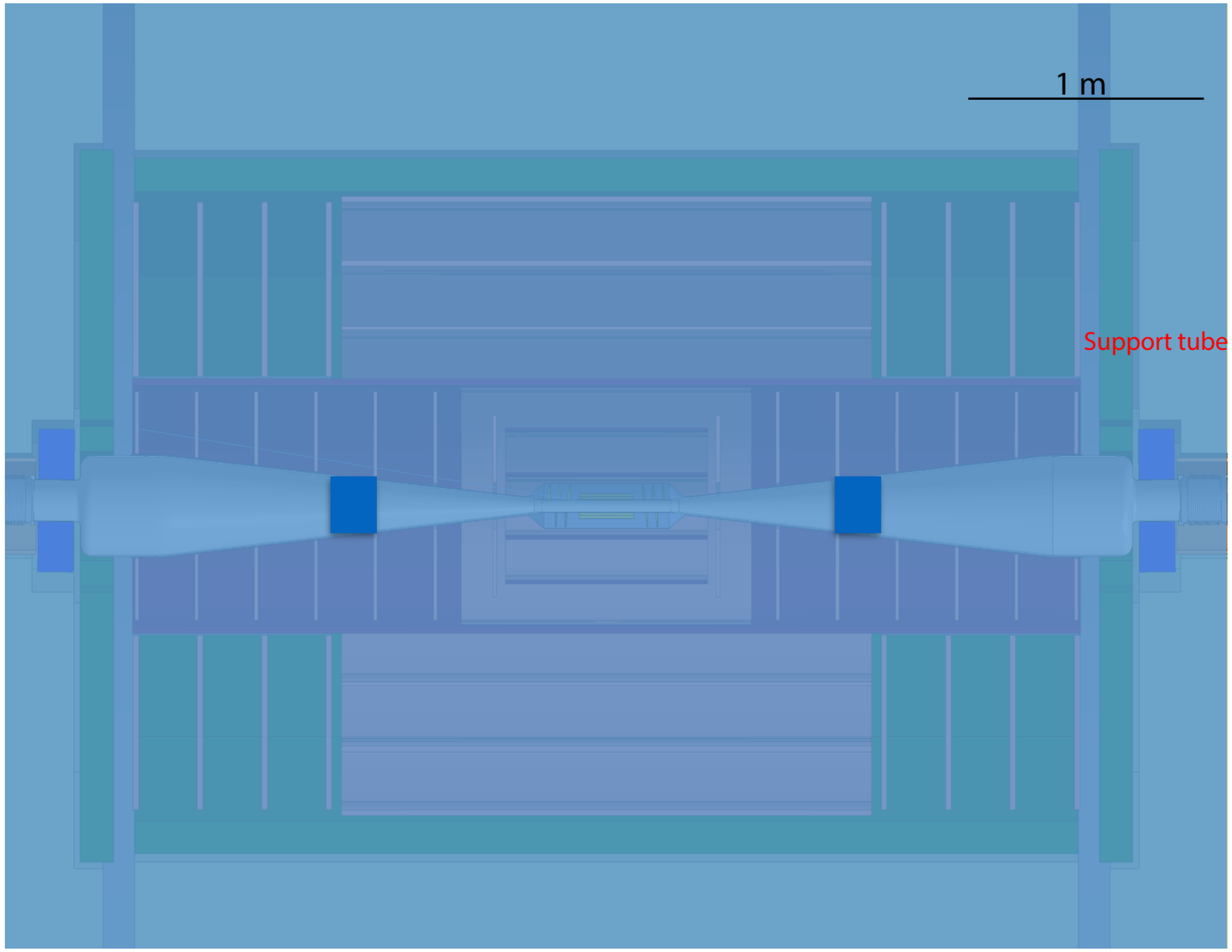
double layer radius [mm]	CLIC	FCC
1st	31-33	17-19
2nd	44-46	37-39
3rd	58-60	57-59

*layer thickness may need to be increased to accommodate water cooling

Disks to replace spirals (no need for air flow)

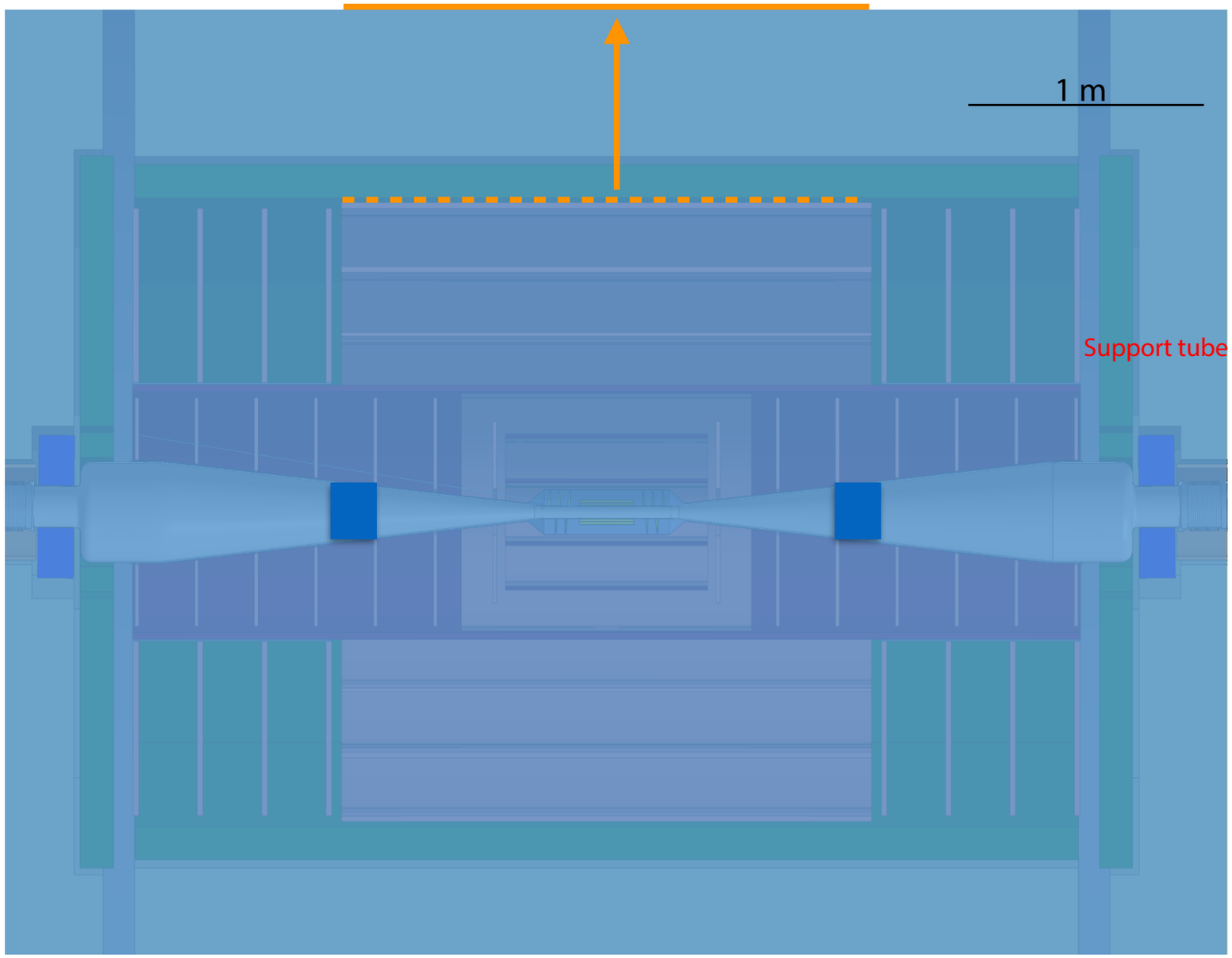
	double disk z [mm]
1st	159-161
2nd	229-231
3rd	299-301

Detector layout/ Tracker



Detector layout/ Tracker

- ☆ OUTER BARREL RADIUS to be increased to 2.14 m
  - ☆ to compensate for the lower B



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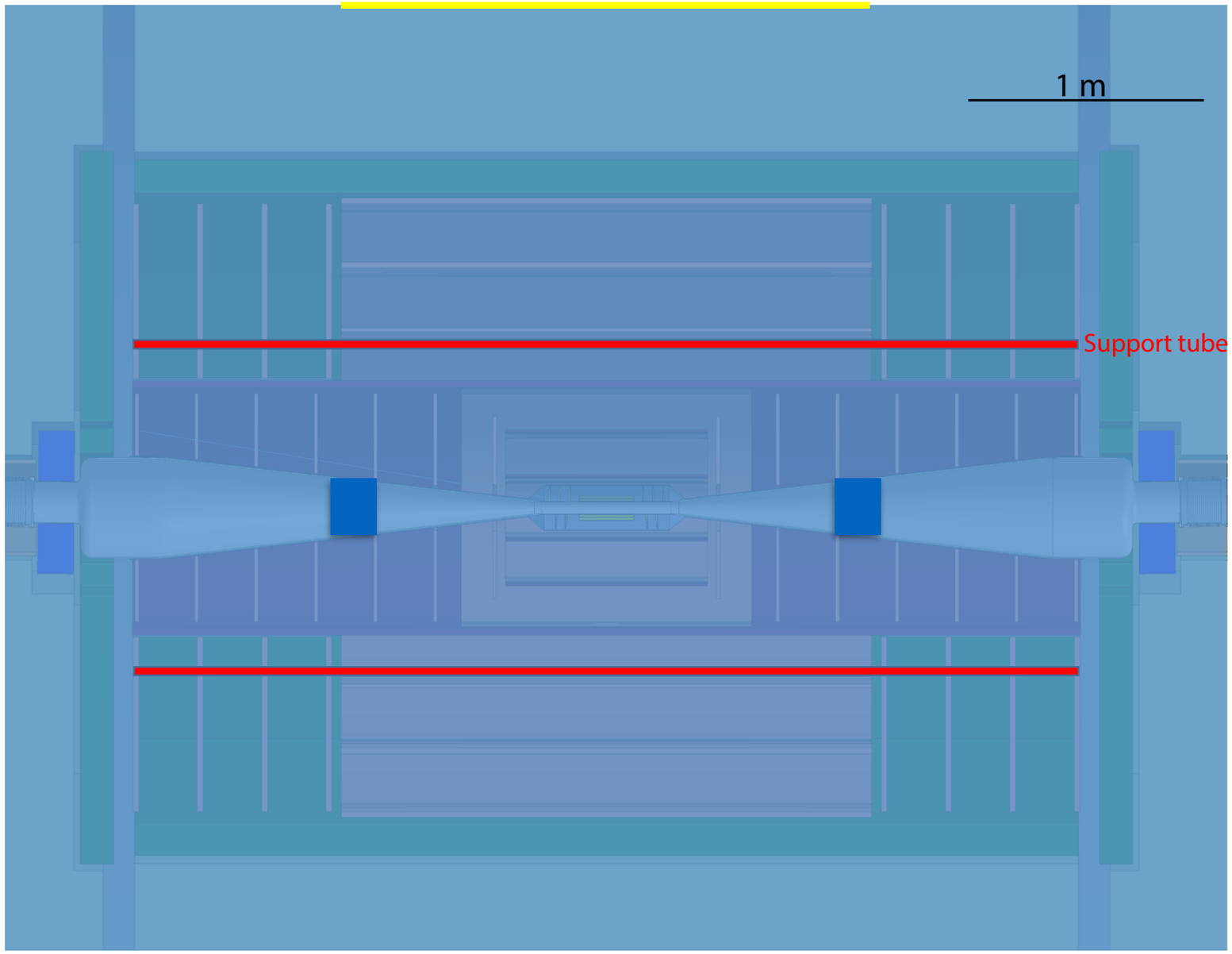


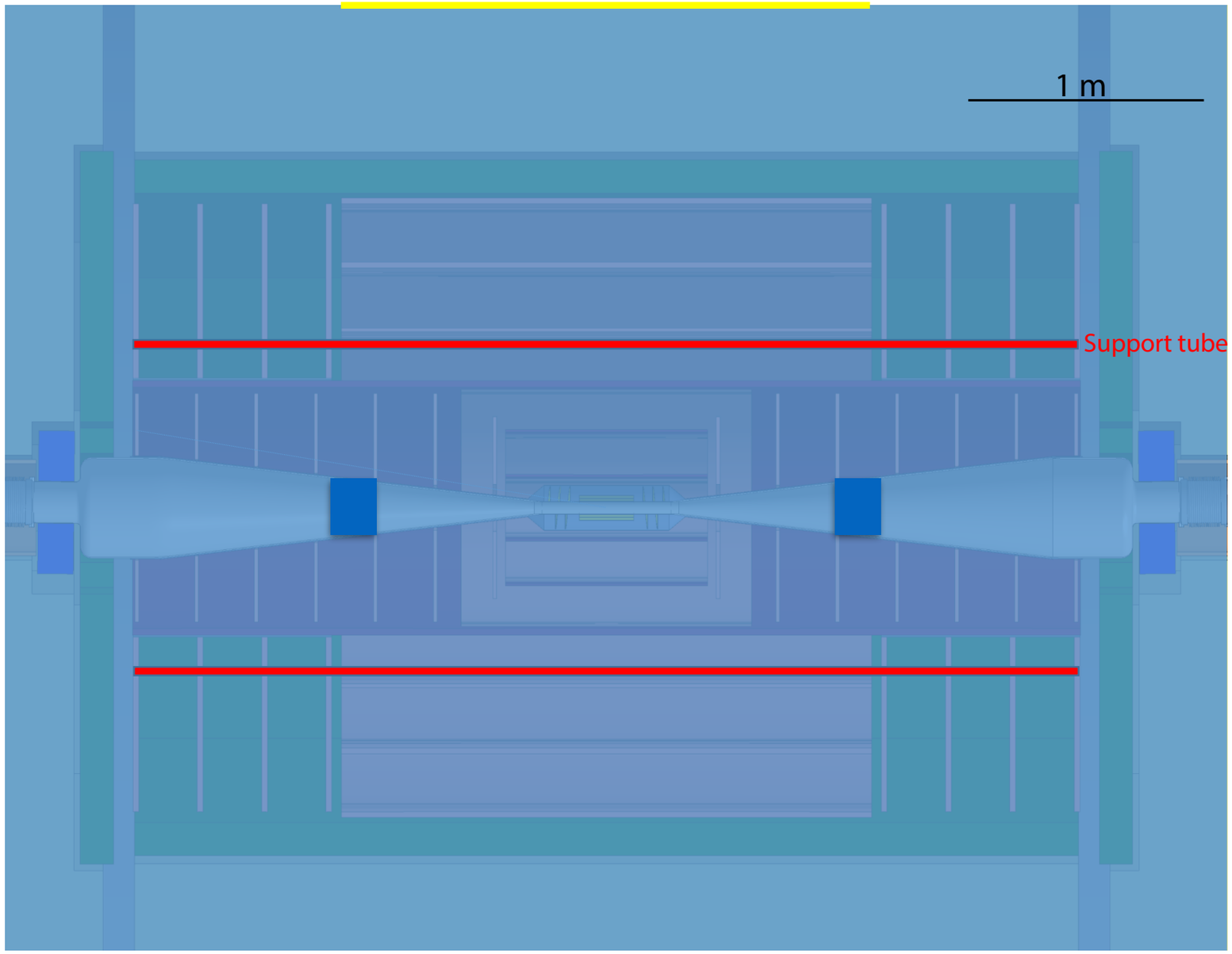
Support tube*

radius [mm]	CLIC	FCC
inner	575	675
outer	600	700

*to be checked for mechanical stability

Detector layout/ Tracker

- OUTER BARREL RADIUS to be increased to 2.14 m
  - to compensate for the lower B



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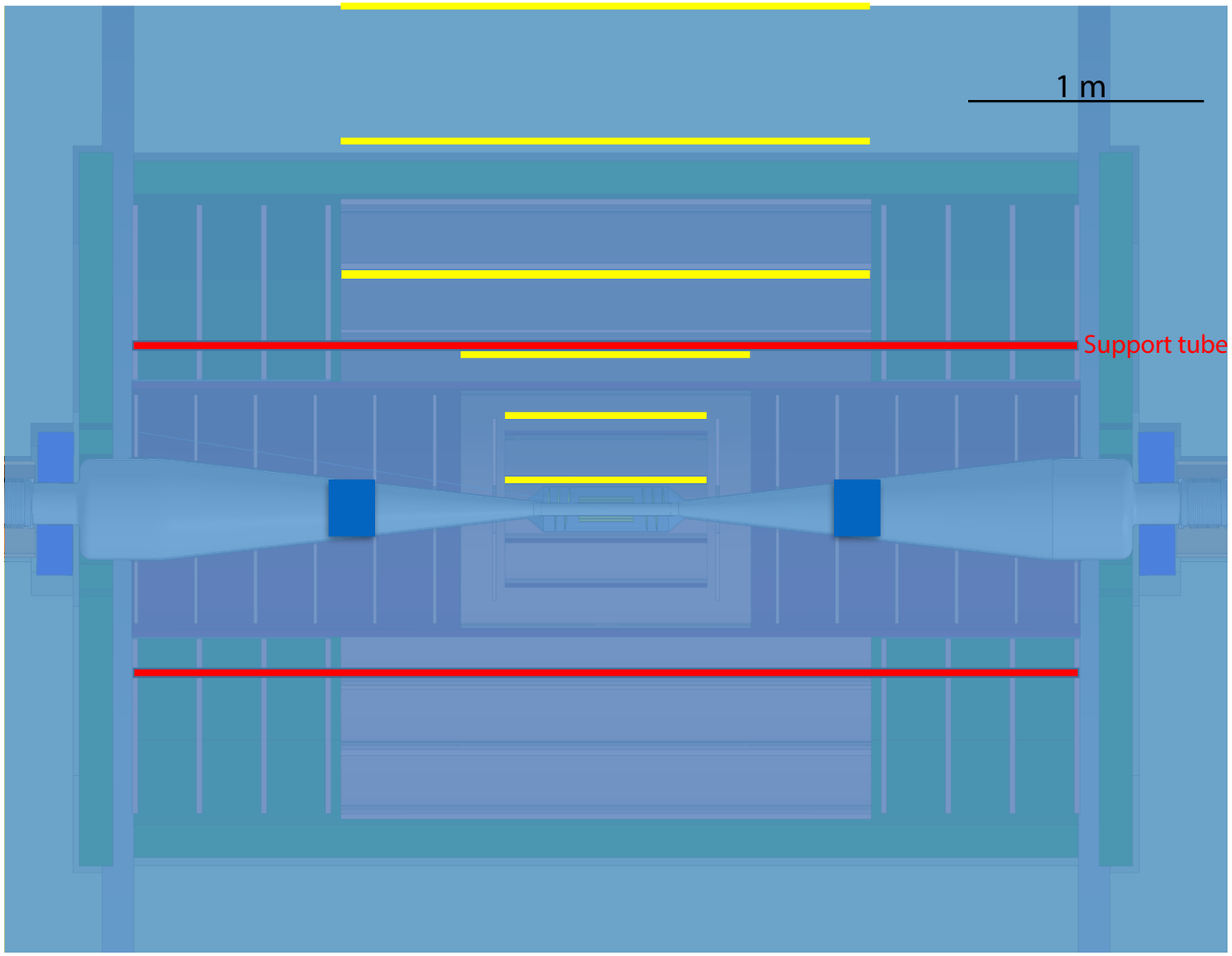

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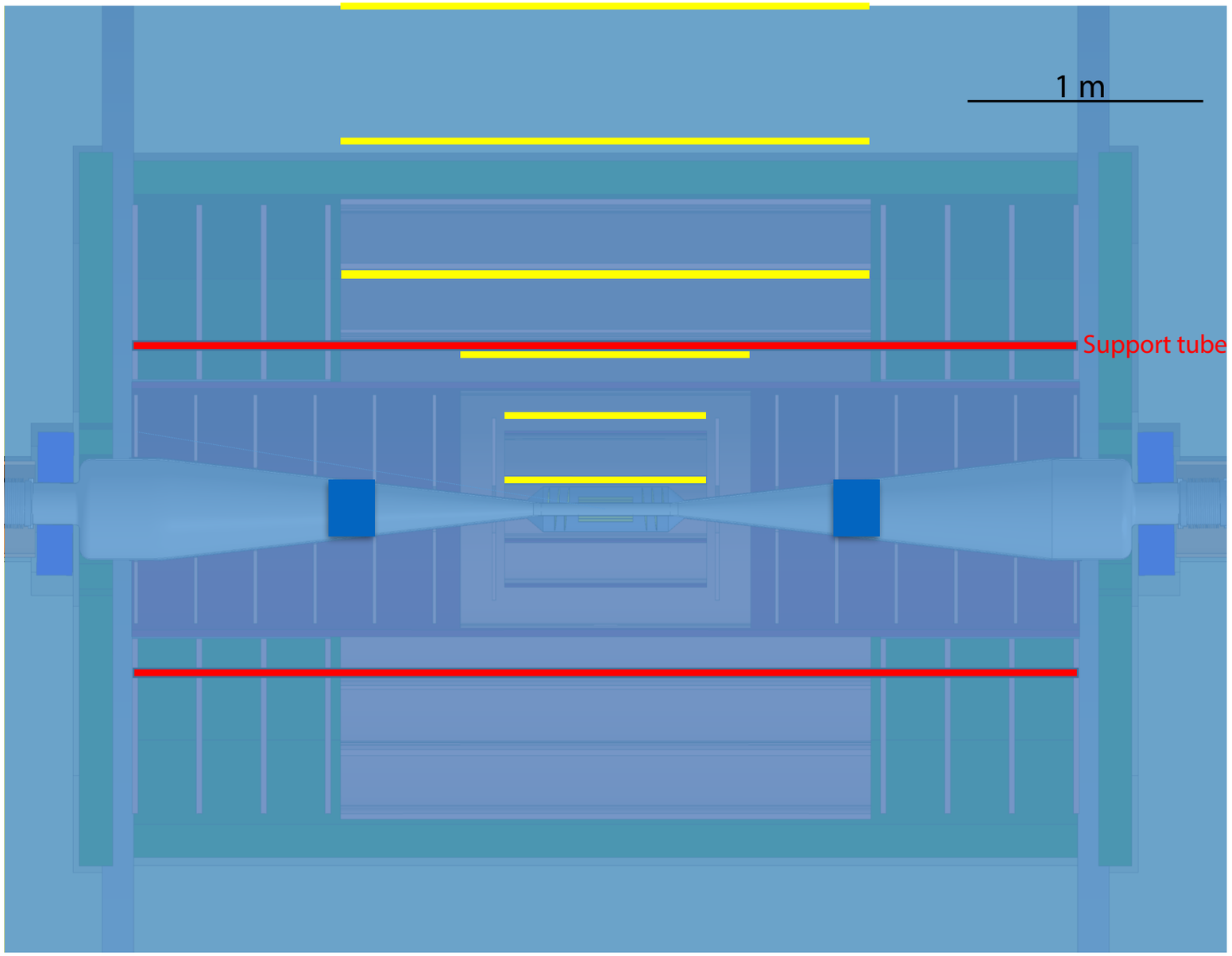


Scale all the barrel layers*

layer radius [mm]	CLIC	FCC
ITB1	127	127
ITB2	340	400
ITB3	554	670
OTB1	819	1000
OTB2	1153	1550
OTB3	1486	2100

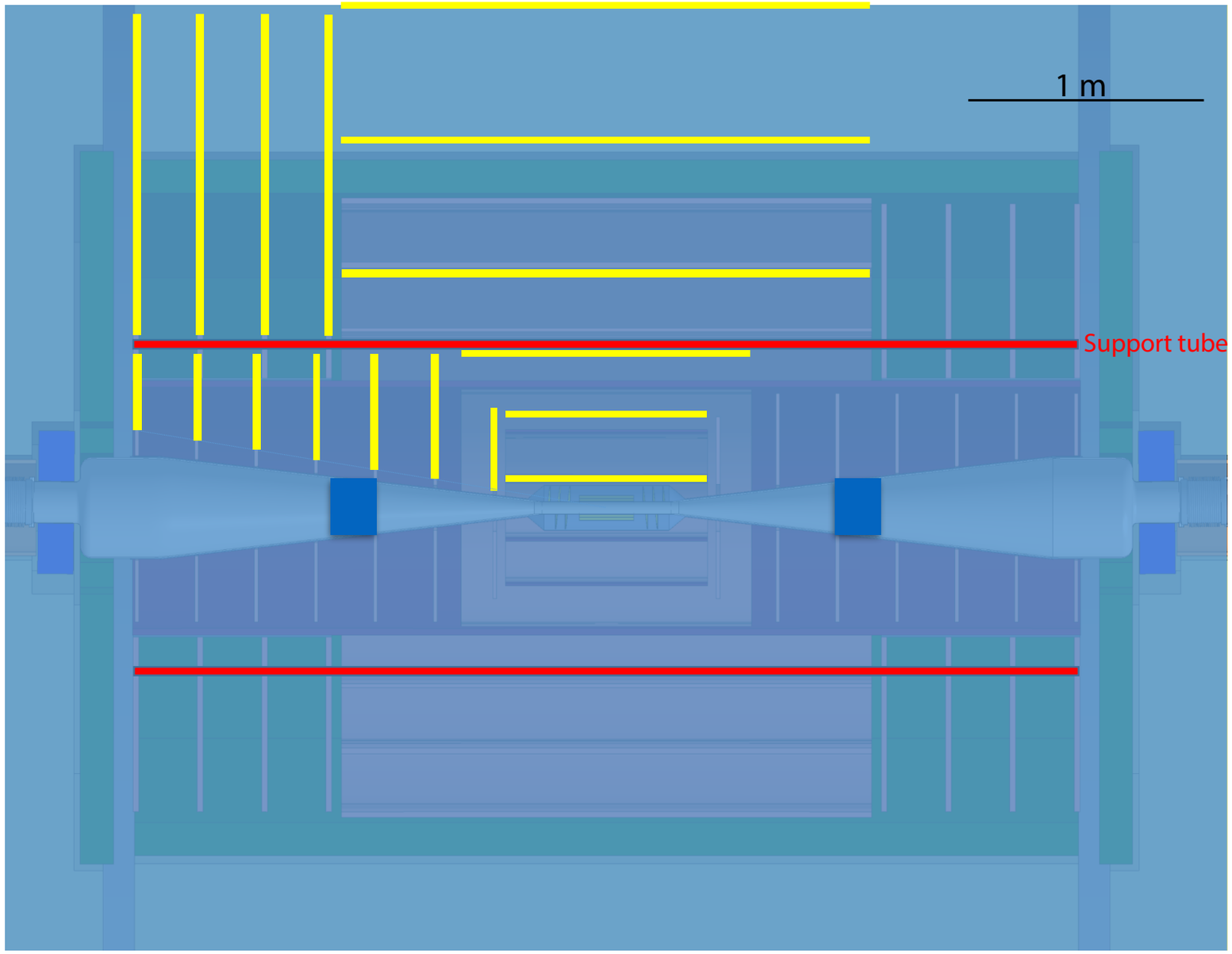
*layer thickness may need to be increased to accommodate more water cooling

Support tube*

radius [mm]	CLIC	FCC
inner	575	675
outer	600	700

*to be checked for mechanical stability

Detector layout/ Tracker

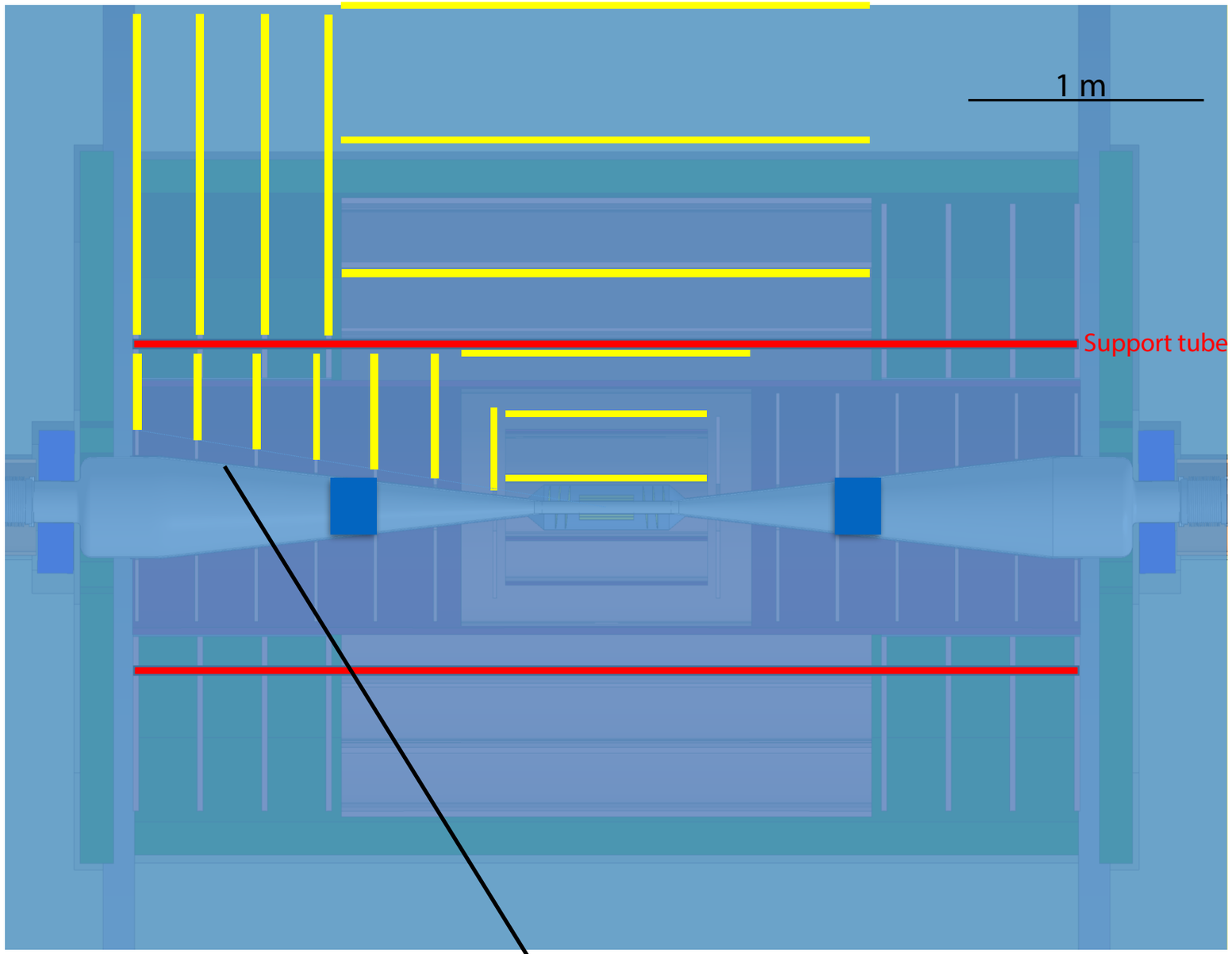


Scale all the disks sizes

disk inner radius [mm]	CLIC	FCC
ITD1	72	78
ITD2	99	121
ITD3	131	163
ITD4	164	206
ITD5	197	249
ITD6	231	291
ITD7	250	328
OTD1-4	618	718

disk outer radius [mm]	CLIC	FCC
ITD1	404	460
ITD2	551	652
ITD3	554	652
ITD4	542	652
ITD5	544	652
ITD6	548	652
ITD7	552	652
OTD1-4	1430	2080

Detector layout/ Tracker



Inner tracker disks — min radius down to 150 mrad

Scale all the disks sizes

disk inner radius [mm]	CLIC	FCC
ITD1	72	78
ITD2	99	121
ITD3	131	163
ITD4	164	206
ITD5	197	249
ITD6	231	291
ITD7	250	328
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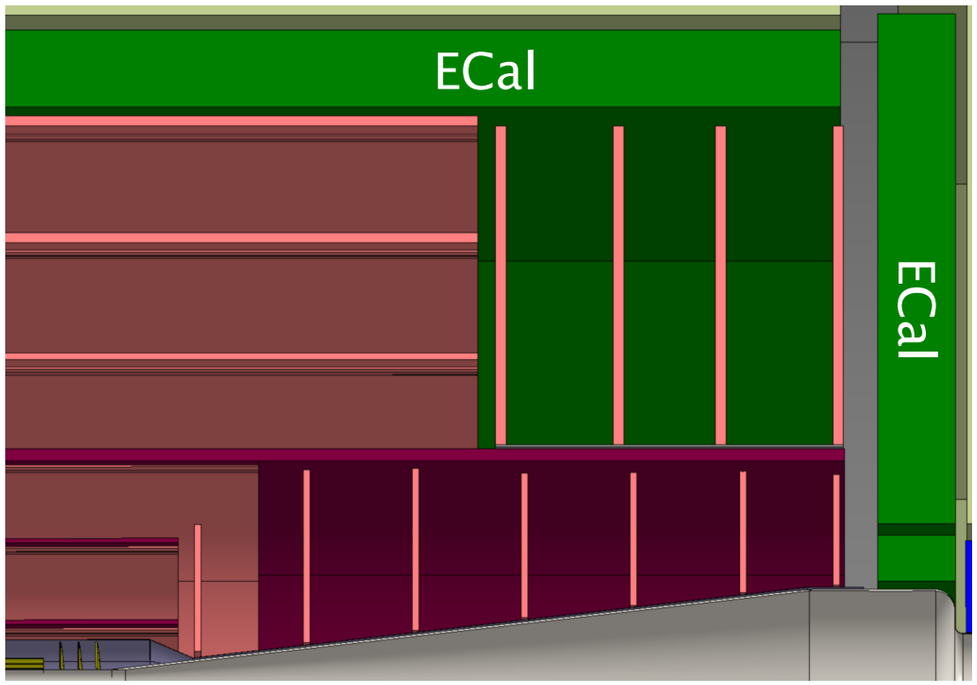
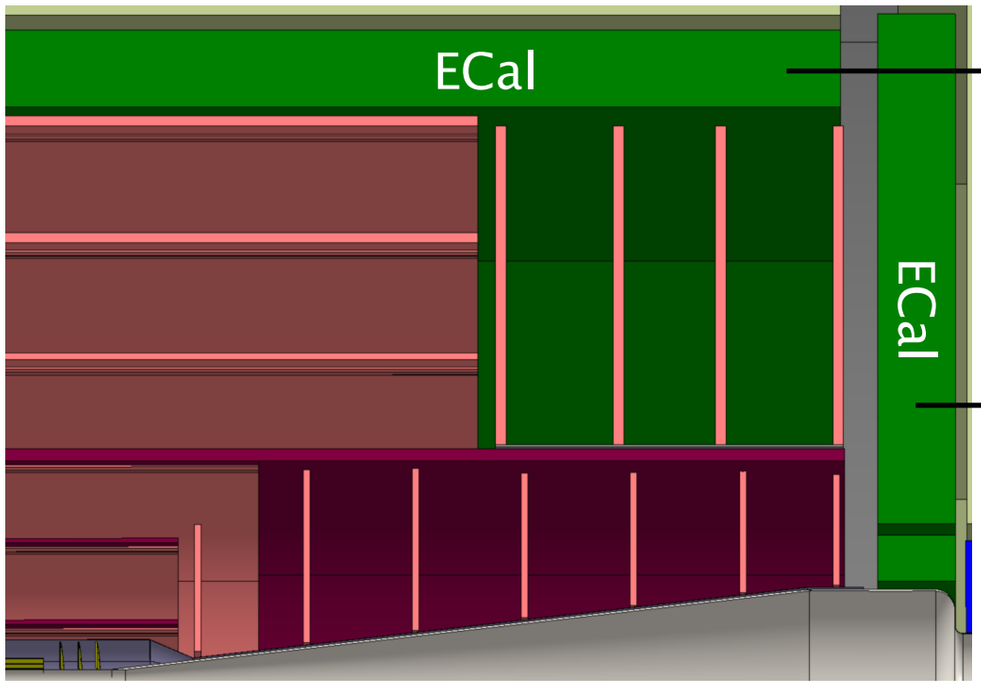
ITD7	552	652
OTD1-4	1430	2080

Detector layout/ ECal



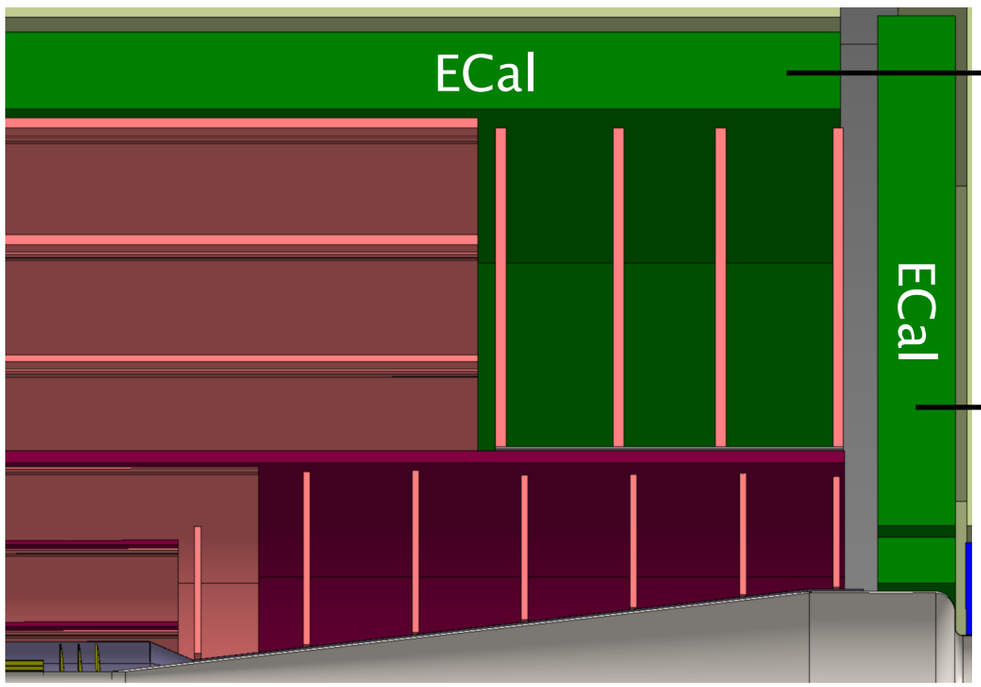
Detector layout/ ECal



- ECal BARREL INNER RADIUS changed to 2.15m
  - due to larger tracker

- ECal ENDCAP
  - z position unchanged
  - transverse size adjusted
    - inner radius = 250mm -> available space?
    - outer radius = 2.35 m

Detector layout/ ECal



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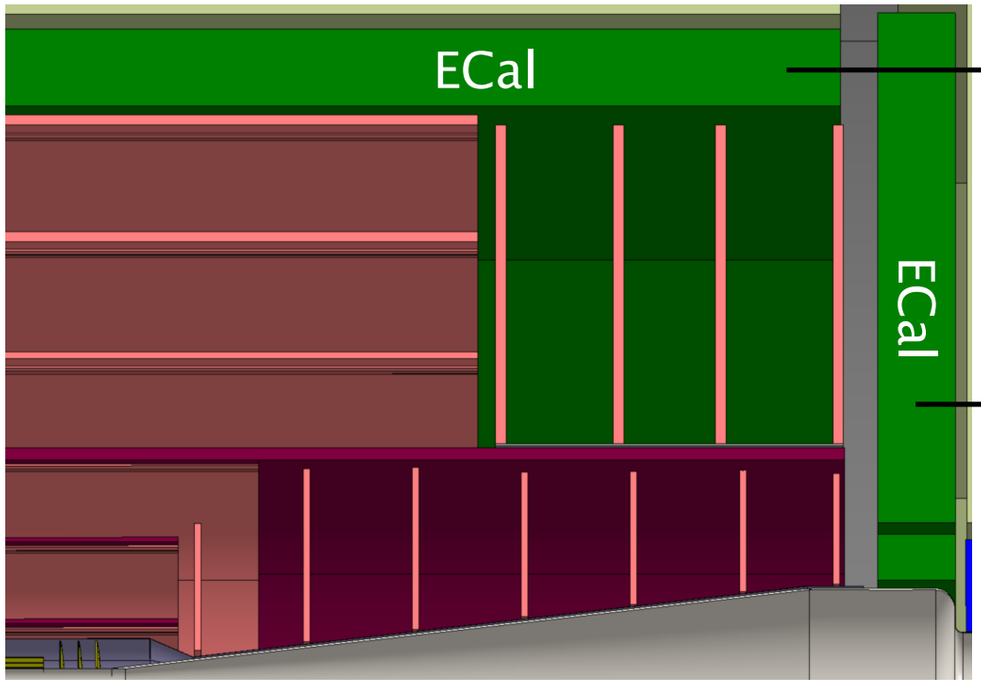
- STRUCTURE unchanged:
  - SiW sampling calorimeter
  - Cell size: 5x5 mm^2
  - Number of radiation lengths: 22 X0
  - Number of layers: 40

- DISTANCE BETWEEN LAYERS: might have to be revised due to need for cooling => sampling fraction will be worse

Detector layout/ ECal



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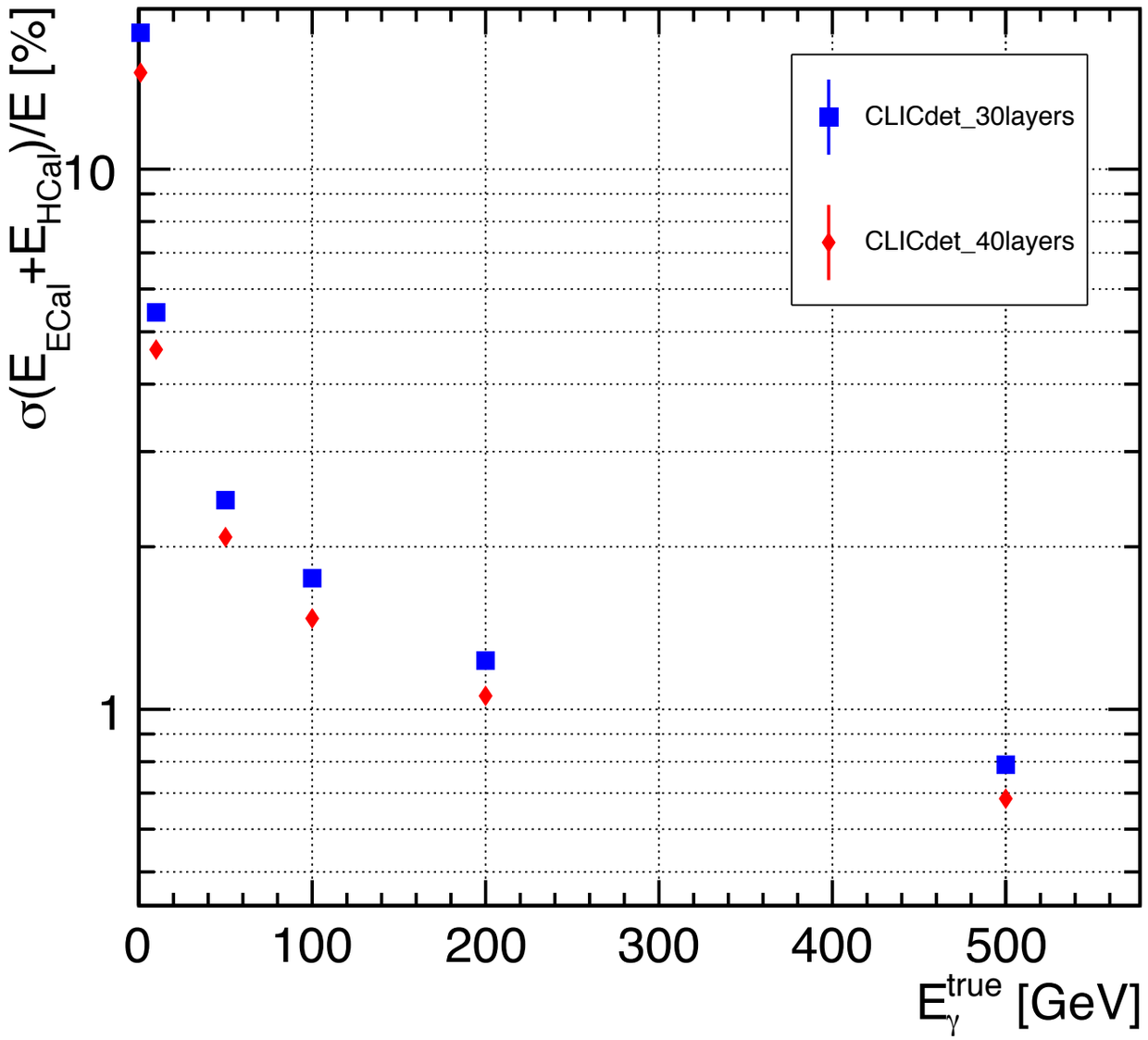
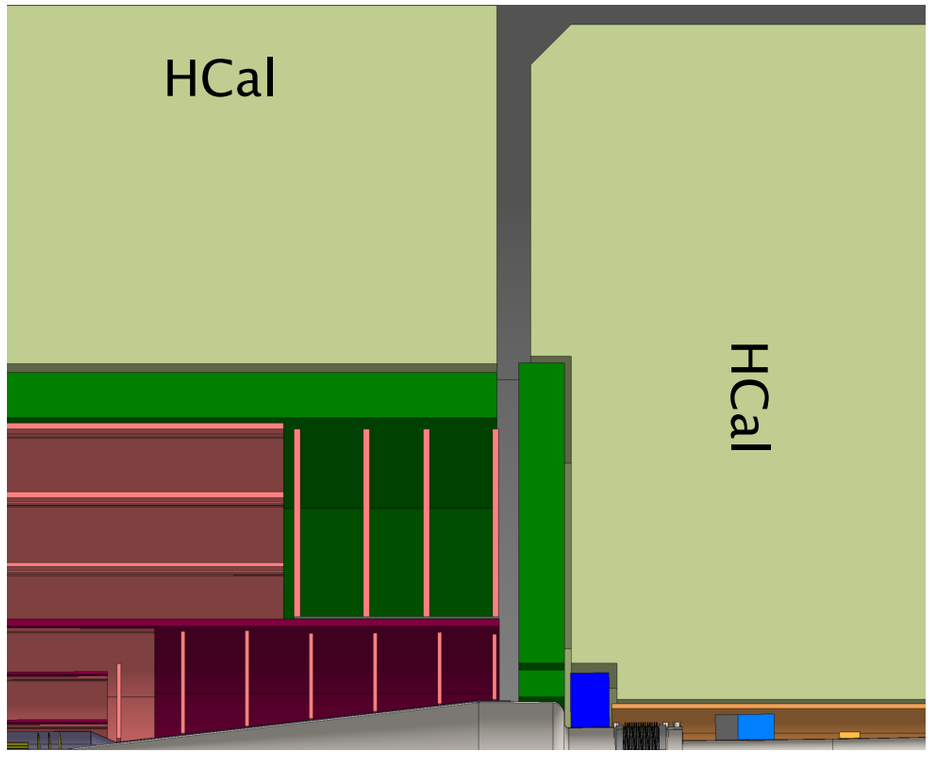
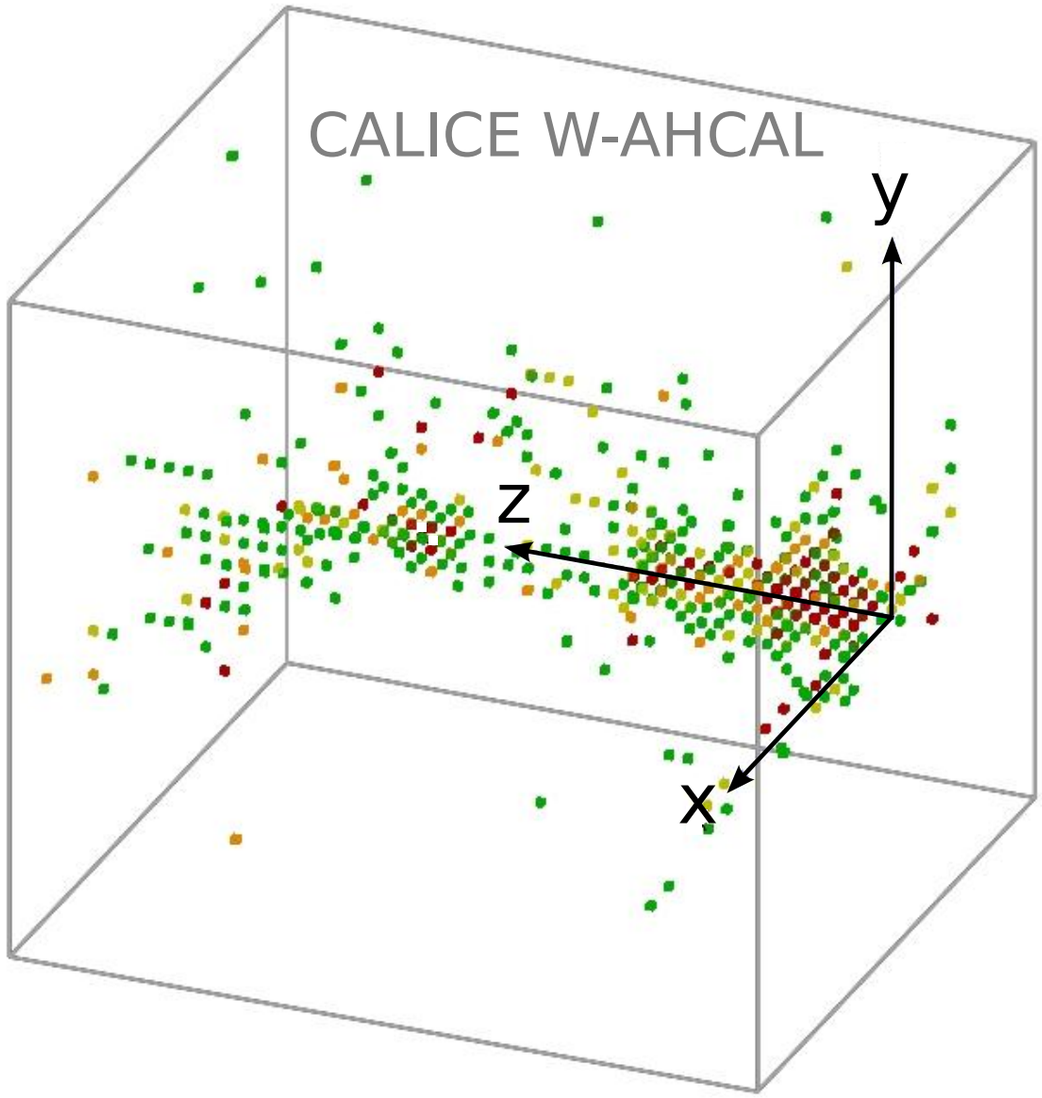


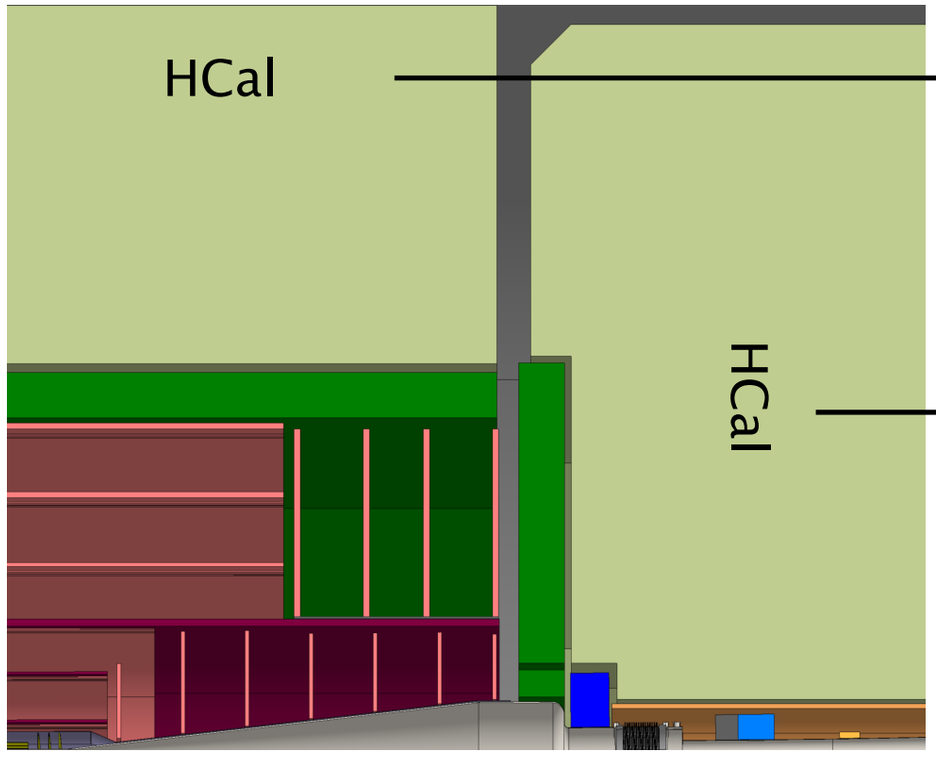
Detector layout/ HCal



- STRUCTURE unchanged:
  - steel + scintillator sampling calorimeter



Detector layout/ HCal



- HCal BARREL INNER RADIUS changed to 2.4m
  - due to larger tracker

- HCal ENDCAP
  - size adjusted
    - outer radius = 3.57 m
    - outer z = 3.71 m (CLIC: 4.13 m)

- STRUCTURE unchanged:
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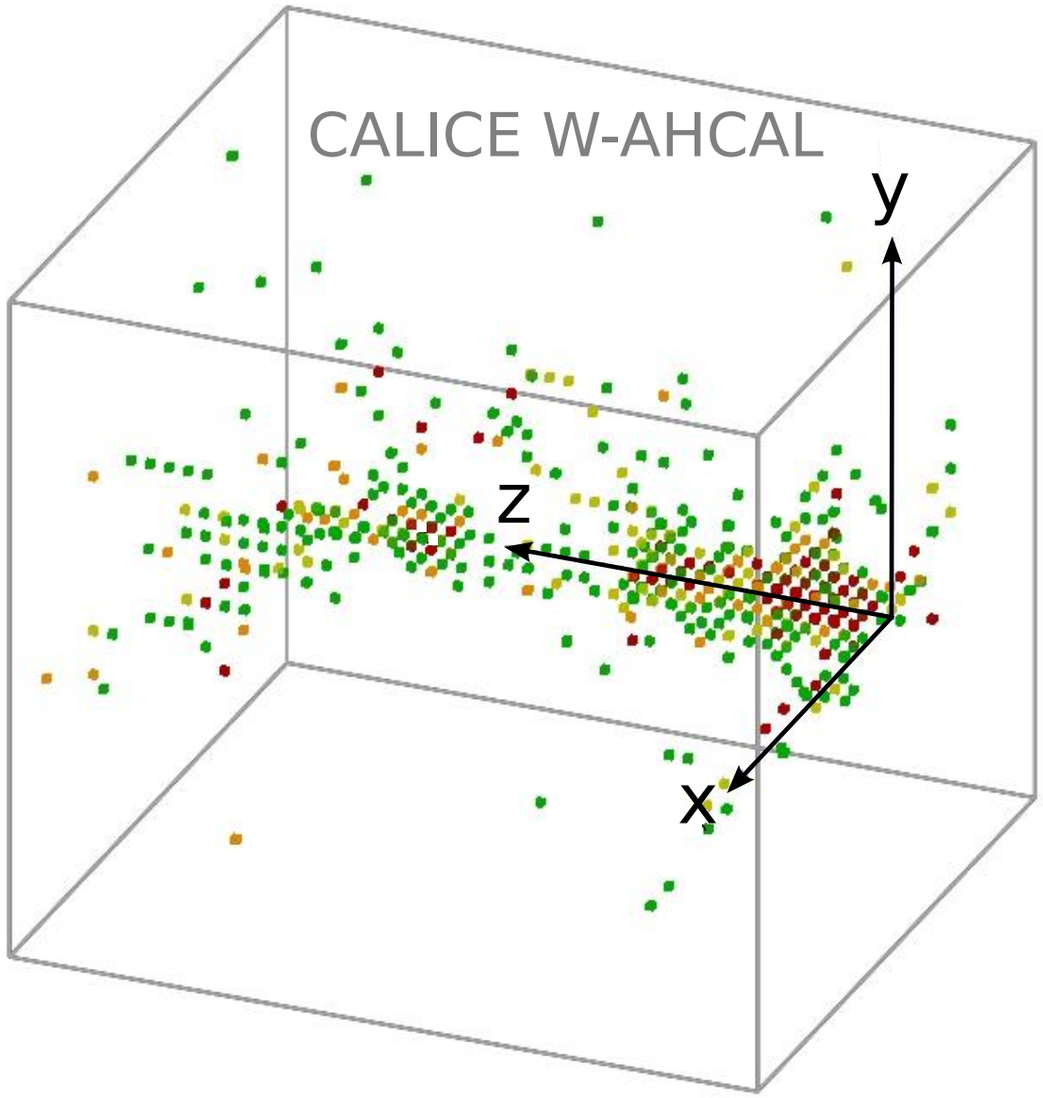
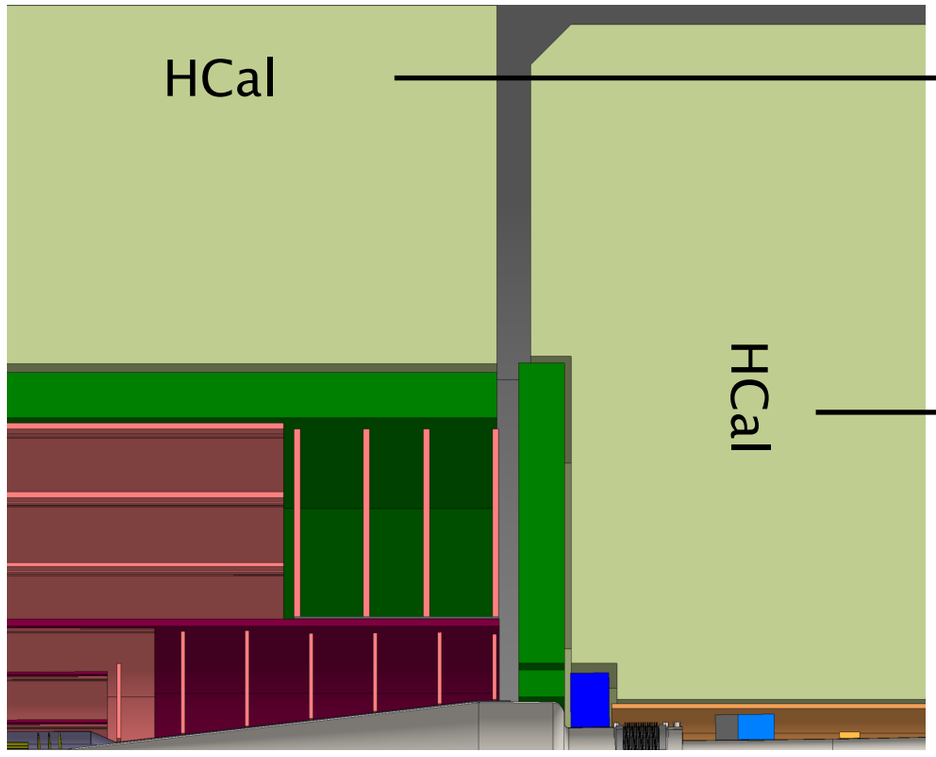


Detector layout/ HCal



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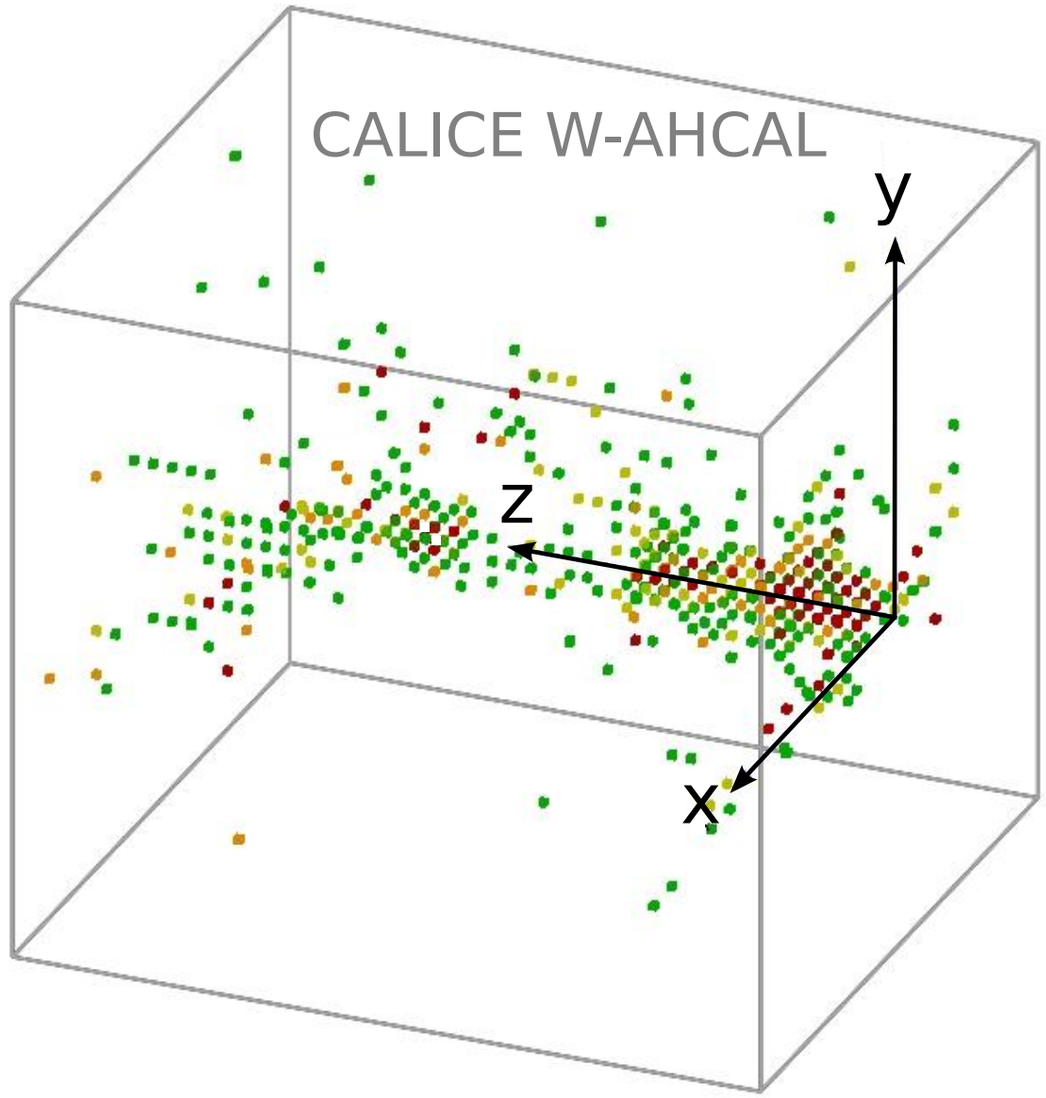
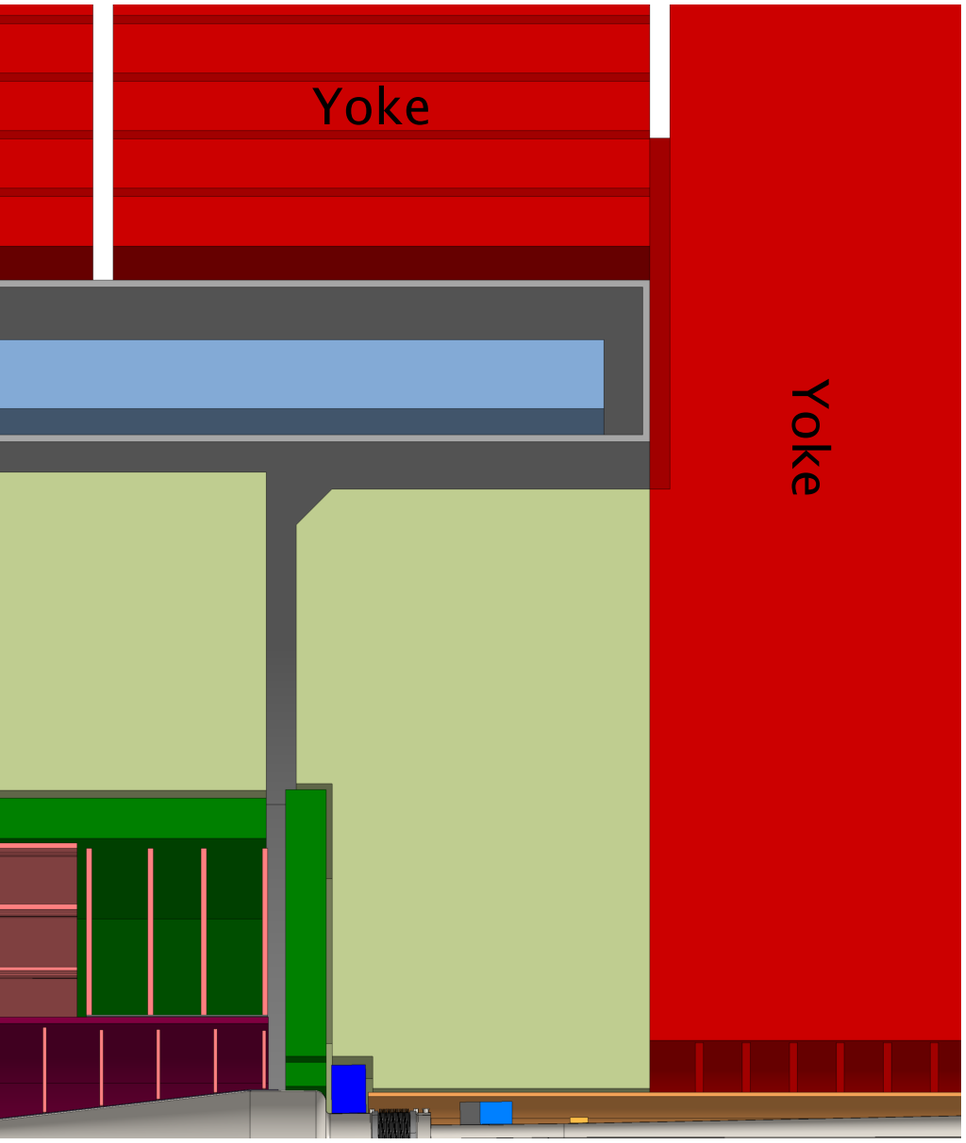


- STRUCTURE unchanged:
  - steel + scintillator sampling calorimeter

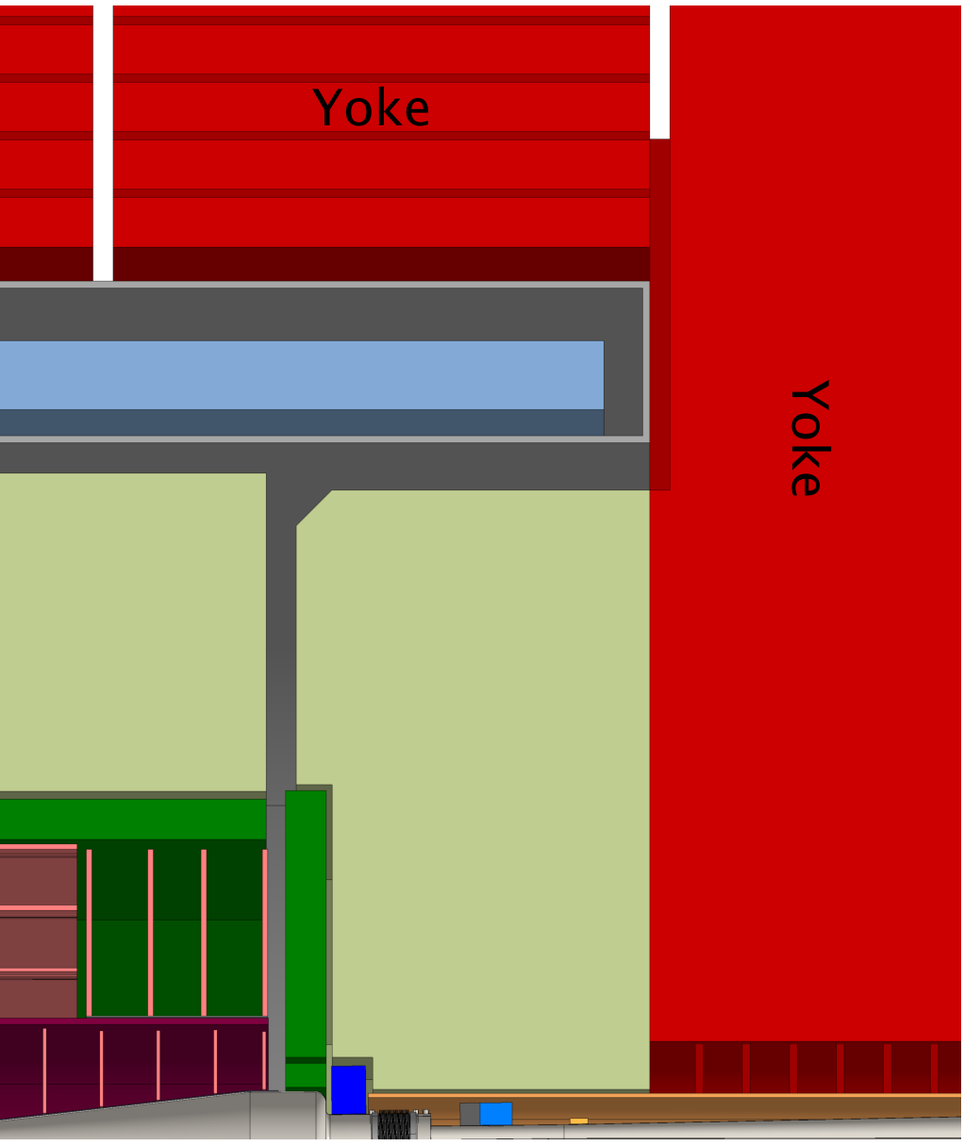
- Segmentation adjusted:
  - Number of layers: 44
  - Number of interaction lengths: 5.5 λ_0
    - CLIC: 7.5 λ_0
    - ILD: 5.5 λ_0 (optimized for 500GeV => similar energy scale as FCC)

Detector layout/ Yoke and Muon ID System

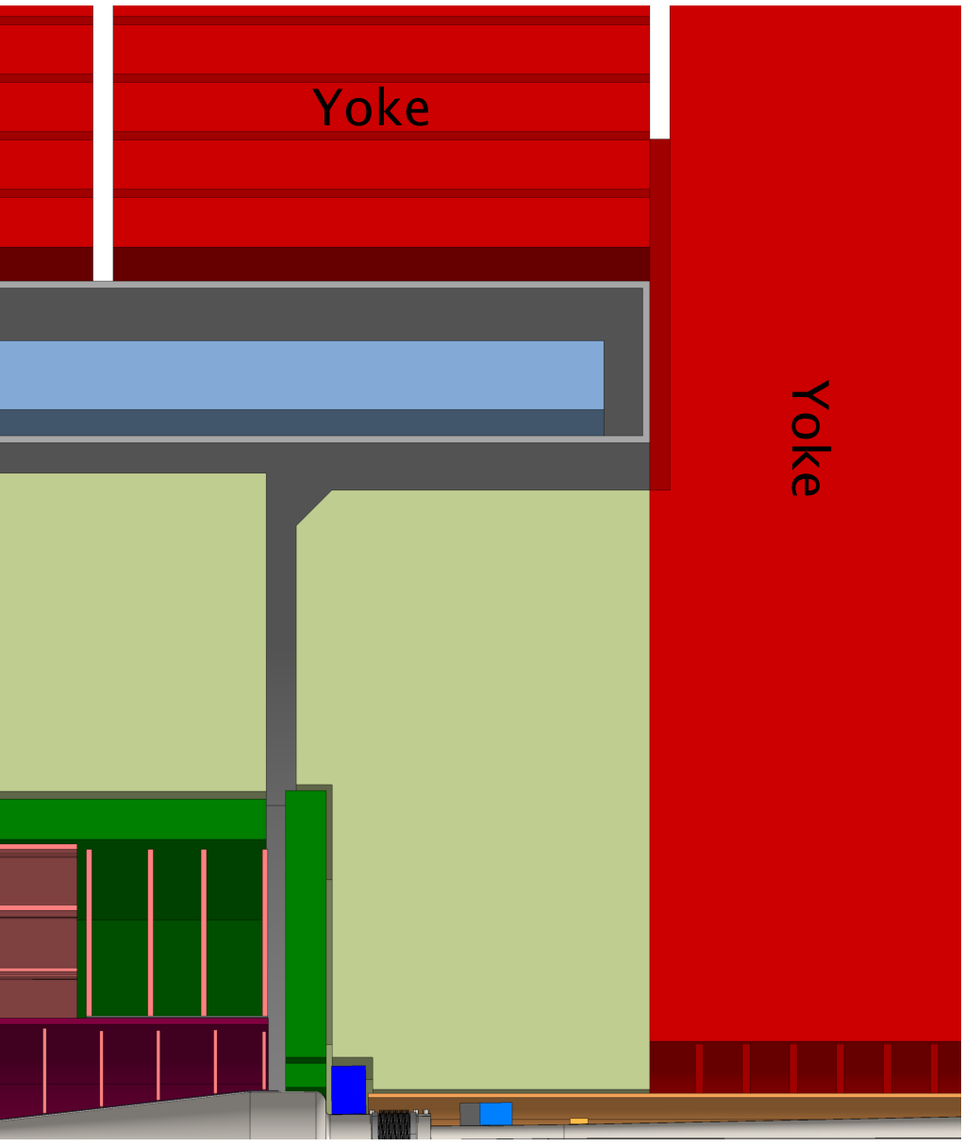


Detector layout/ Yoke and Muon ID System

- ☆ Yoke shields stray field, especially along the beam
  + improves muon ID

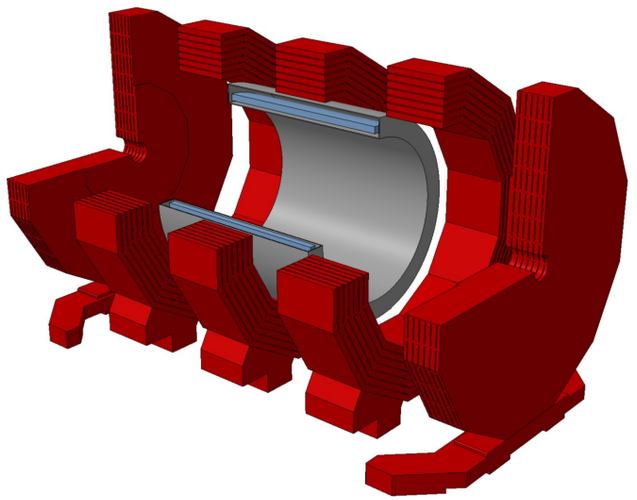


Detector layout/ Yoke and Muon ID System



- ☆ Yoke shields stray field, especially along the beam + improves muon ID

- ☆ STRUCTURE unchanged:
- ☆ Fe yoke equipped with muon chambers
  - ☆ RPCs 30x30 mm^2
  - ☆ 7 layers equally spaced



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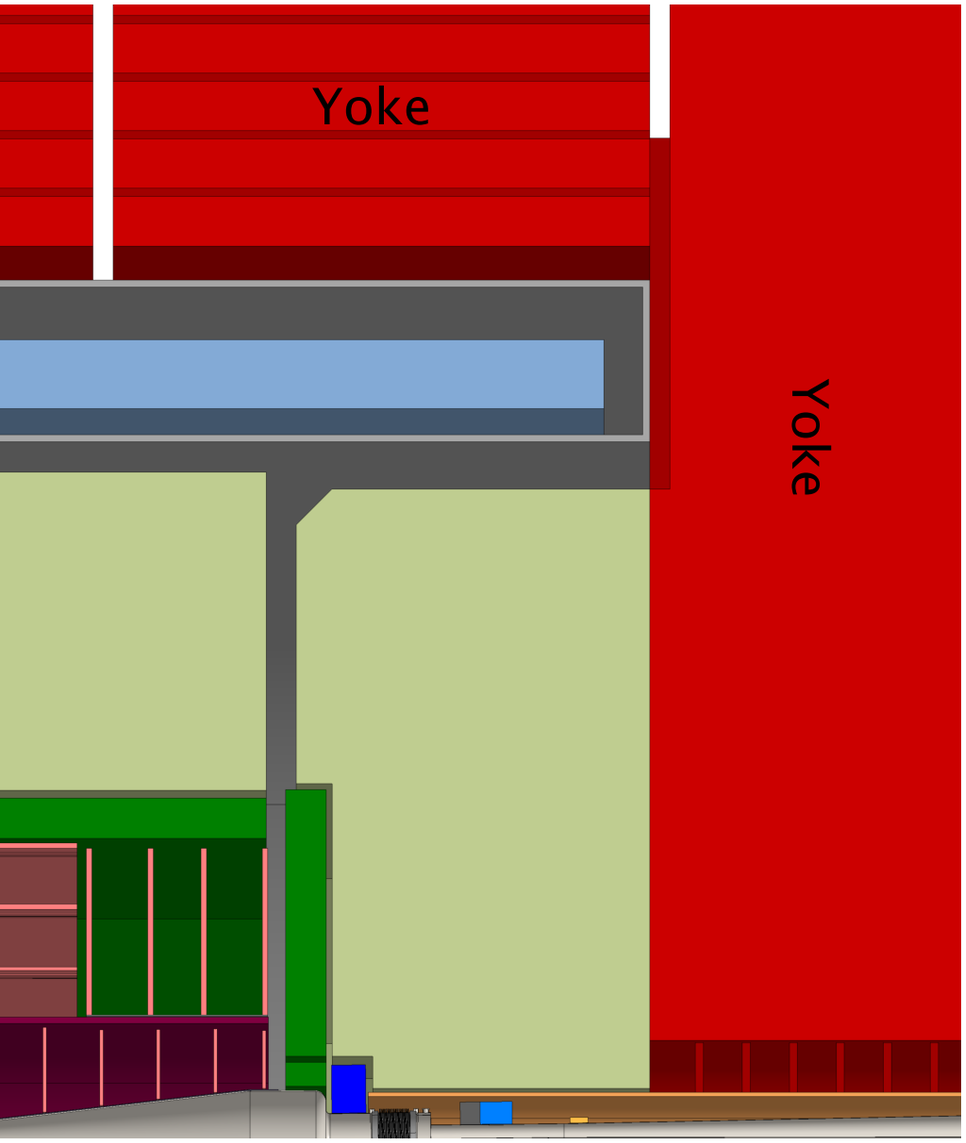

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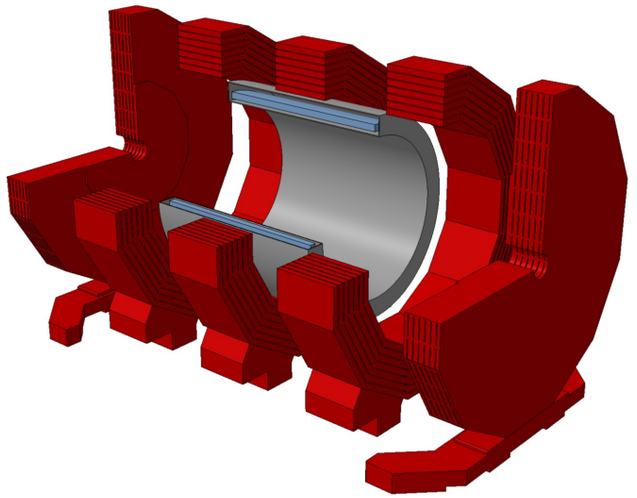


- ☆ Size and position adjusted
  - ☆ scaled out due to larger tracker
  - ☆ thinner for smaller B

YOKE BARREL

radius [m]	CLIC	FCC
inner	4.46	4.48
outer	6.45	6.00

YOKE ENDCAPS

z [m]	CLIC	FCC
inner	4.18	3.76
outer	5.70	5.30

radius [m]	CLIC	FCC
inner	0.49	0.40
outer	6.45	6.00

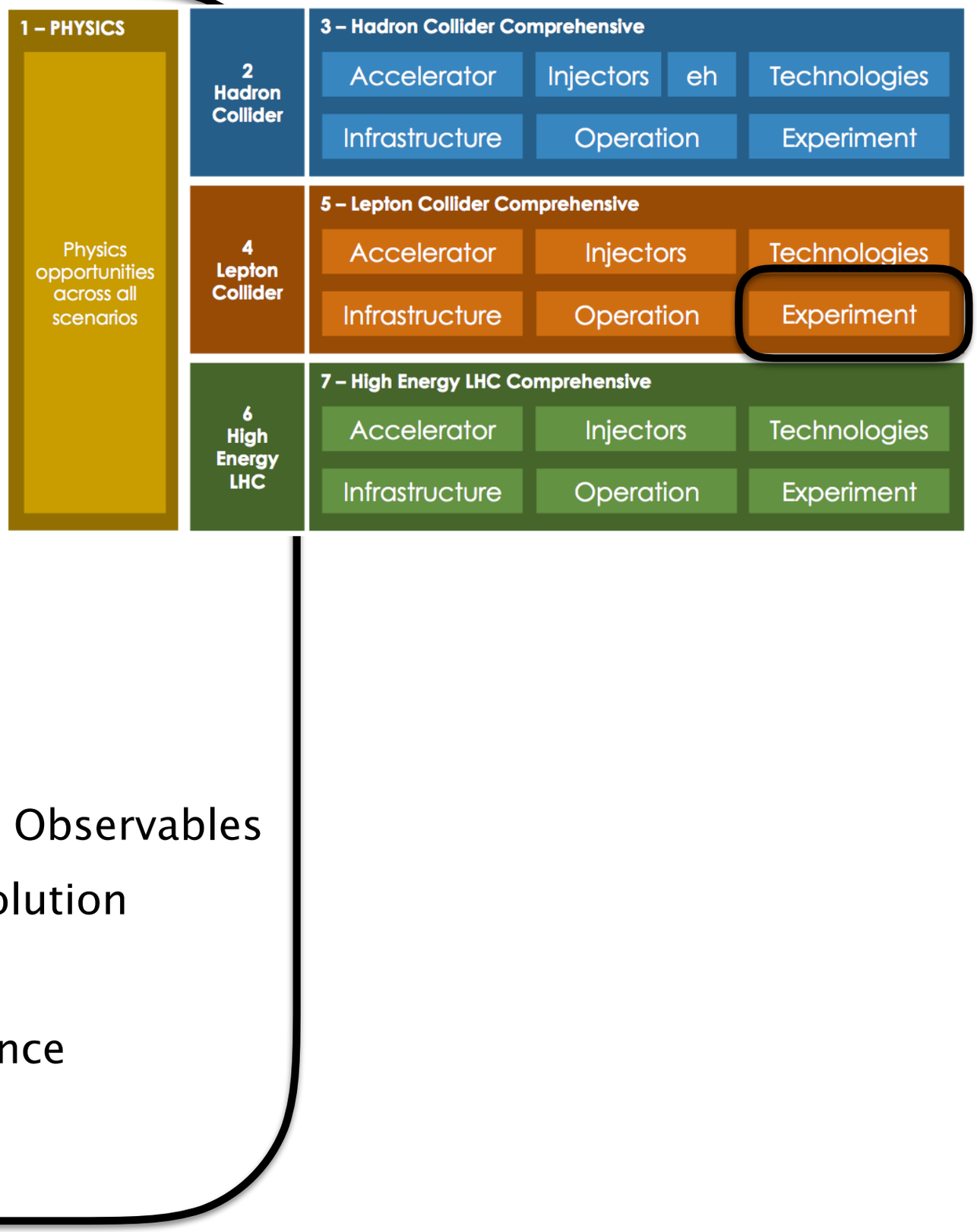
Next steps

- Impact of background hits to be investigated
- Thickness of vertex/tracker layers
  - examine the coverage (Nhits vs polar angle)
  - studies ongoing to determine the effect of increasing the material budget to accommodate the needed additional cooling
  - feasibility of cooling and support structures
- Position of vertex/tracker layers
  - performance studies (momentum resolution, tracking efficiency) ongoing
- Longitudinal segmentation of calorimeters
  - may need to be revised to accommodate the needed additional cooling
- Dimensions of yoke and muon identification system

Part of the CDR Vol. 5: Lepton Collider/Experiment

A CLIC-inspired detector for FCC-ee

1. Overview
2. Vertex Detectors
3. Tracking System
4. Calorimetry
   - 4.1 Electromagnetic Calorimeter
   - 4.2 Hadronic Calorimeter
5. Yoke and Muon Identification System
6. Physics Performance
   - 6.1 Simulation and Reconstruction
   - 6.2 Performance for Lower Level Physics Observables
     - 6.2.1 Muon and Electron Energy Resolution
     - 6.2.2 Jet Reconstruction
     - 6.2.3 Particle Identification Performance
     - 6.2.4 Flavour Tagging



Part of the CDR Vol. 5: Lepton Collider/Experiment

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   - 4.1 Electromagnetic Calorimeter
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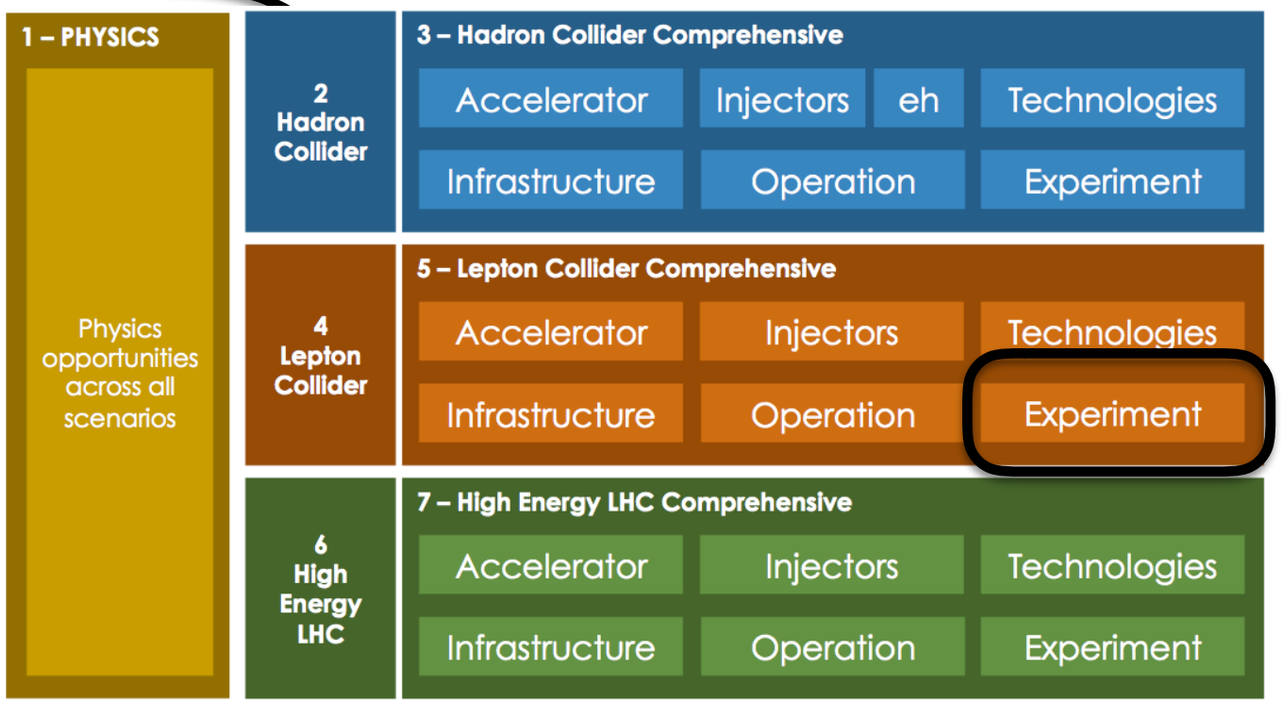
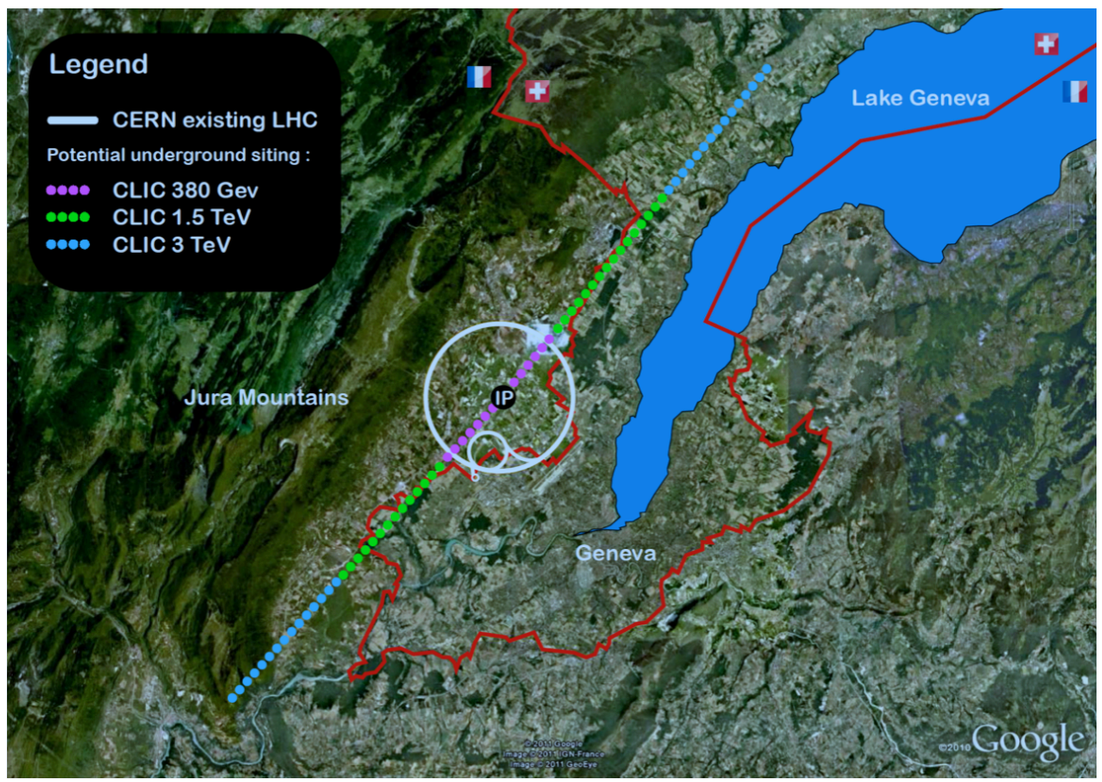


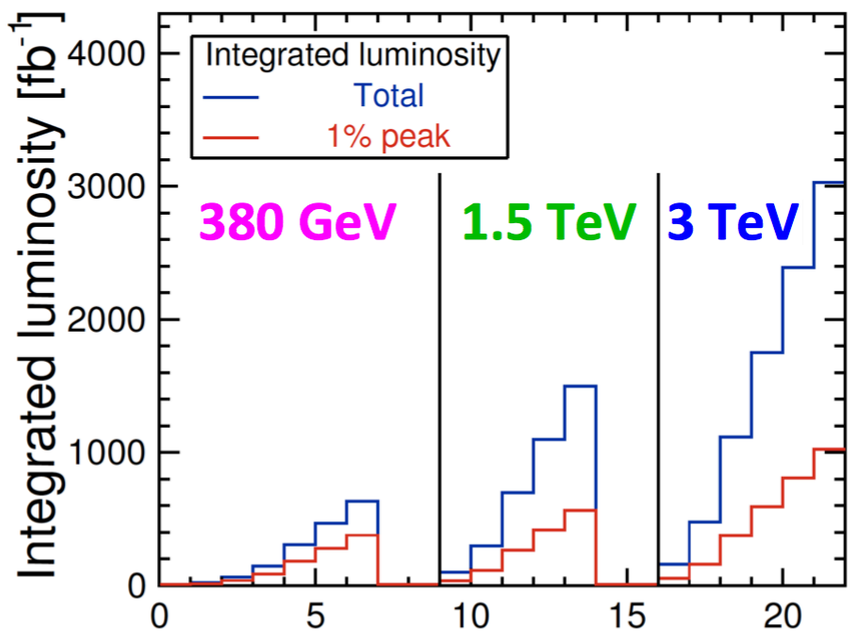
Thank you
for your attention

BACKUP

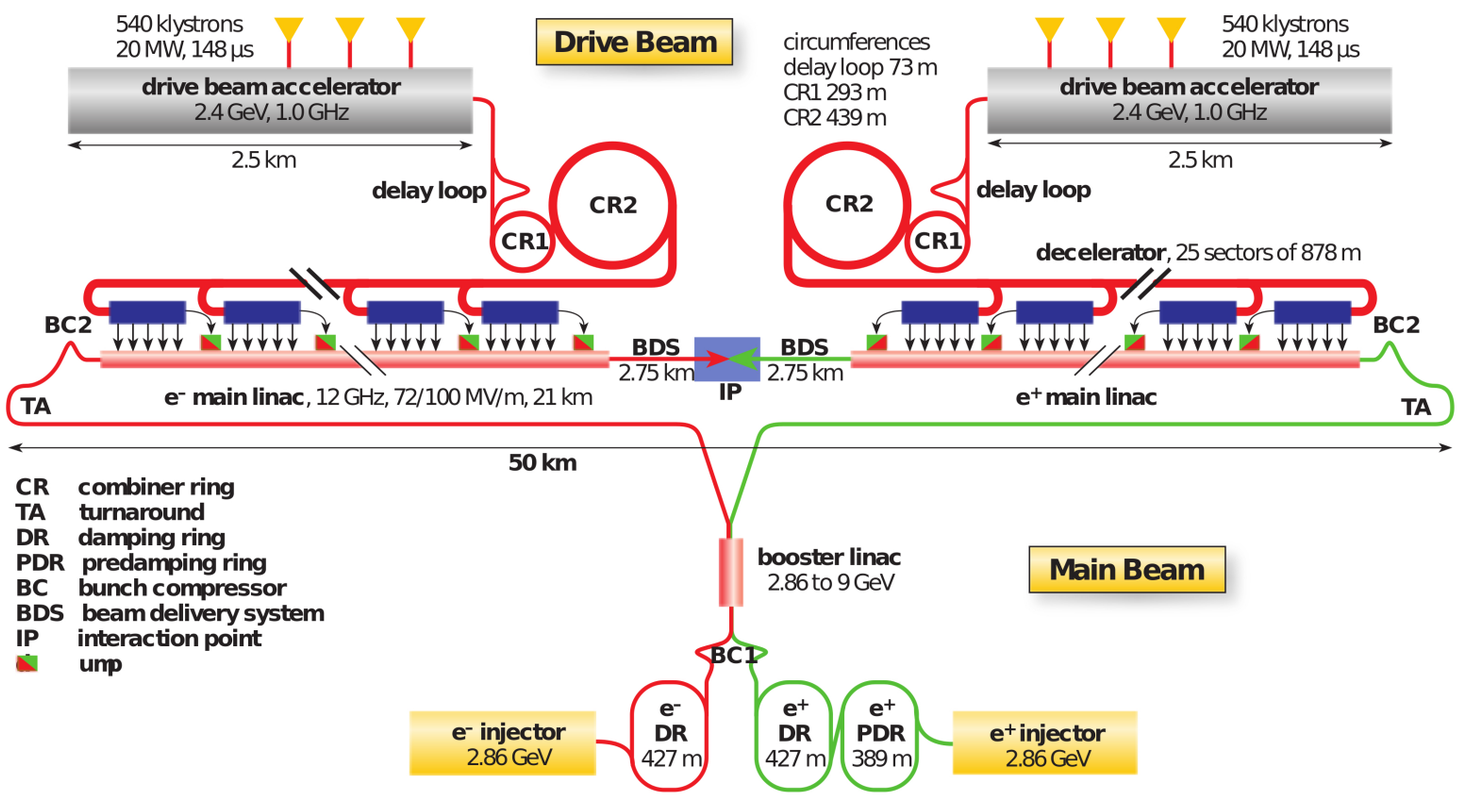
CLIC/ Beam conditions



Staging scenario: 11km, 29km, 50km



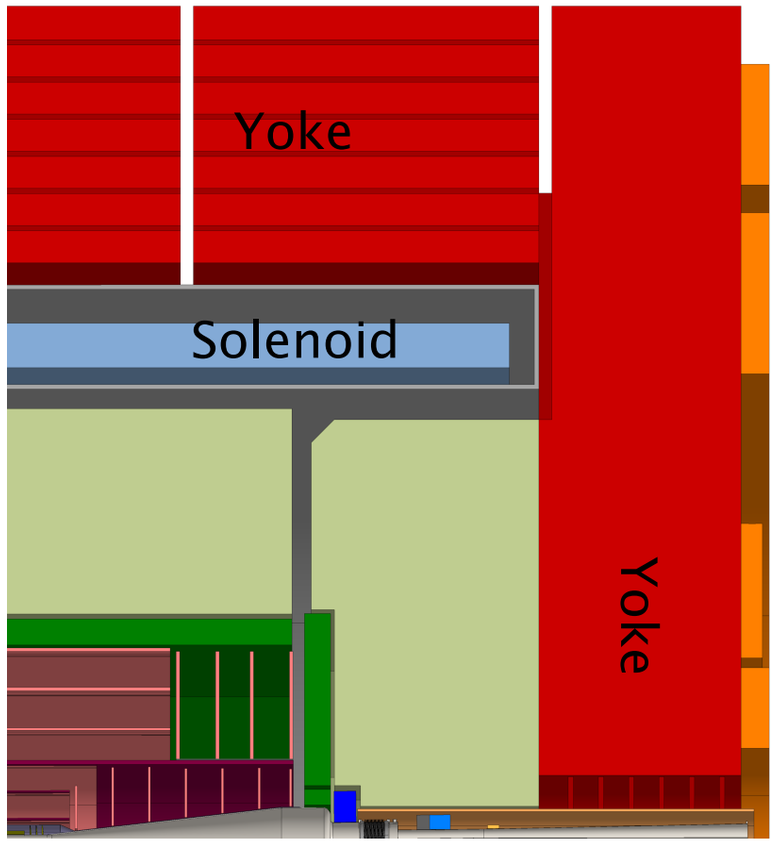
Two-beam acceleration scheme at 12 GHz, gradient of 100MV/m



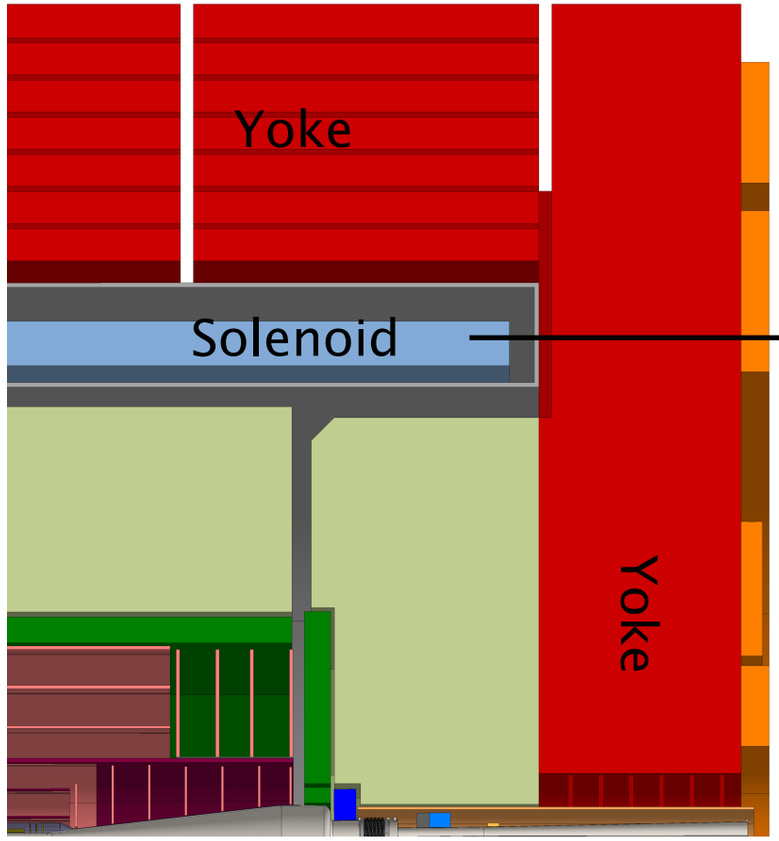
Detector layout/ Vertex and Tracker sensitive areas

subdetector	CLIC sensor area [m^2]	FCC sensor area [m^2]
VTX barrel	0.487	0.358
VTX endcaps	0.351 (spirals)	0.185 (disks)
ITD1	0.63	0.56
ITD2	1.13	1.29
ITD3	1.10	1.25
ITD4	1.03	1.20
ITD5	0.98	1.14
ITD6	0.94	1.07
ITD7	0.91	1.00
OTD1-4	6.96	11.98
ITB1	0.79	0.77
ITB2	2.20	2.42
ITB3	5.22	5.83
OTB1	14.30	15.88
OTB2	20.32	24.91
OTB3	26.04	33.93

Detector layout/ Solenoid and Magnetic Yoke



Detector layout/ Solenoid and Magnetic Yoke



Coil

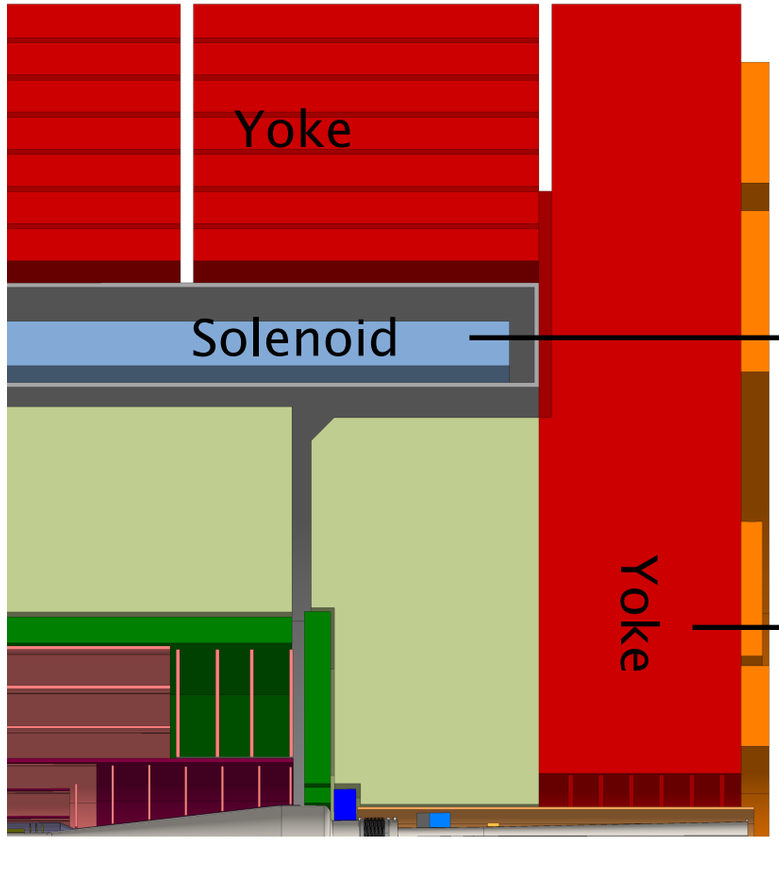
- scaled out due to larger tracker
- thinner for smaller B field

radius [mm]	CLIC	FCC
inner	3649	3885
outer	3993	3975

Vacuum tank

radius [mm]	CLIC	FCC
inner	3483	3719
outer	4290	4272

Detector layout/ Solenoid and Magnetic Yoke



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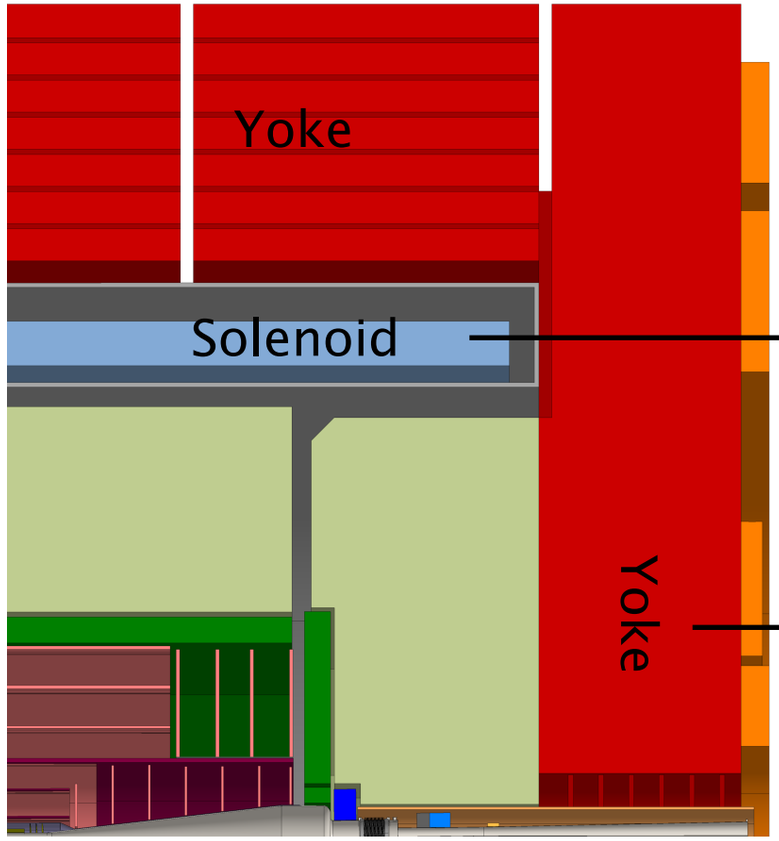
- ☆ Yoke shields stray field, especially along the beam
  + improves muon ID

Detector layout/ Solenoid and Magnetic Yoke



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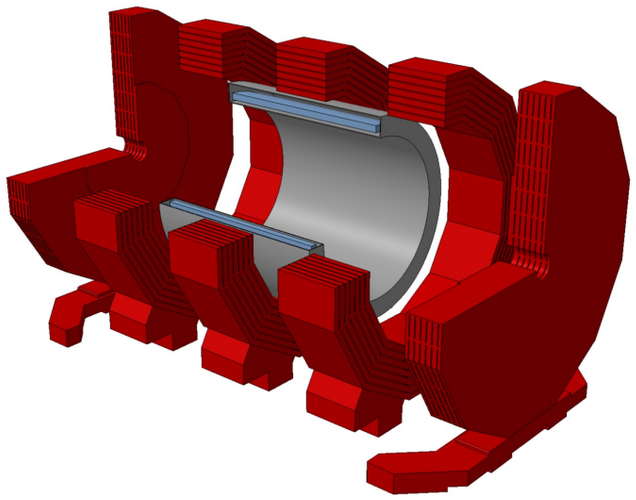
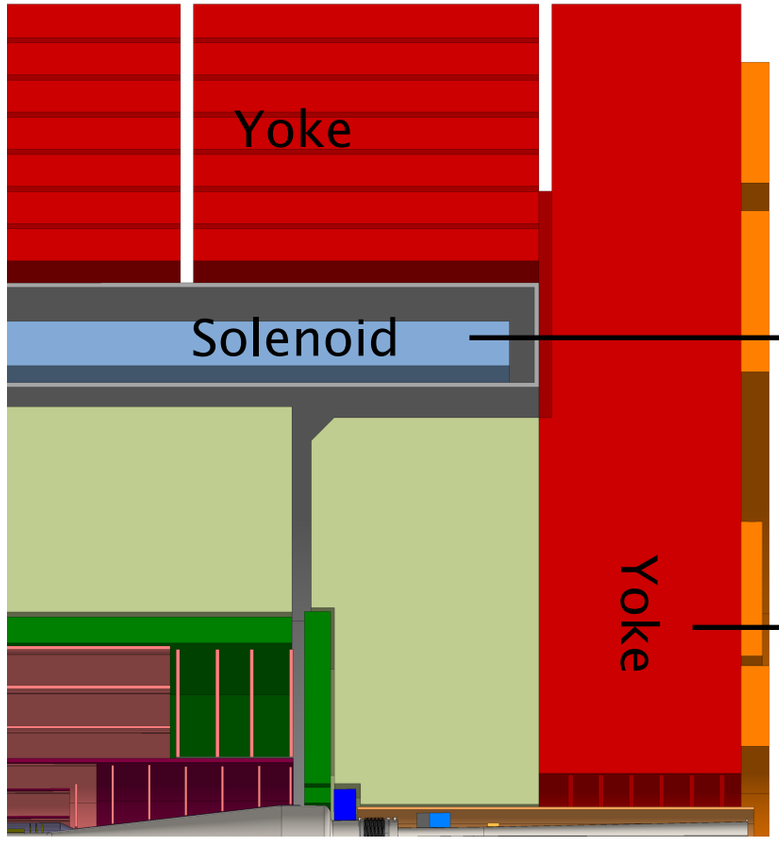
- Yoke shields stray field, especially along the beam
  + improves muon ID

- STRUCTURE unchanged:
- Fe yoke equipped with muon chambers
  - RPCs 30x30 mm^2



Detector layout/ Solenoid and Magnetic Yoke



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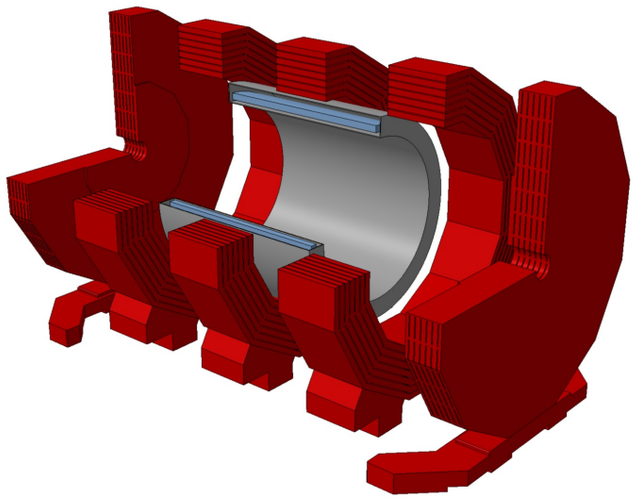

- Size and position adjusted
  - scaled out due to larger tracker
  - thinner for smaller B

BARREL

radius [mm]	CLIC	FCC
inner	4461	4479
outer	6450	6000

ENDCAPS

z [mm]	CLIC	FCC
inner	4179	3755
outer	5700	5300

radius [mm]	CLIC	FCC
inner	490	400
outer	6450	6000