ILD & SiD full simulation models

thanks to SiD and ILD colleagues for their input

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1-2 February, 2022

Full detector simulation plays essential role in:

- reliable estimates of physics potential at future experiments
- understanding the impact of detector design on reconstruction / physics performance
- understanding the impact of
  - machine backgrounds,
    - noise, mis-calibrations,
      - imperfections,
        - acceptance holes,
          - complex corners of detectors, ...

a robust, reliable, useful full simulation model should be sufficiently detailed

with detailed input from detector experts

→ resolutions, material, infrastructure

→ ideally bench-marked against experience from subdetector prototypes

ILD and SiD detectors

designed for particle flow reconstruction

at ILC, e+e- @ E_{CM} = (91), 250, 500, (1000) GeV

ILC physics imposes performance goals:

momentum resolution

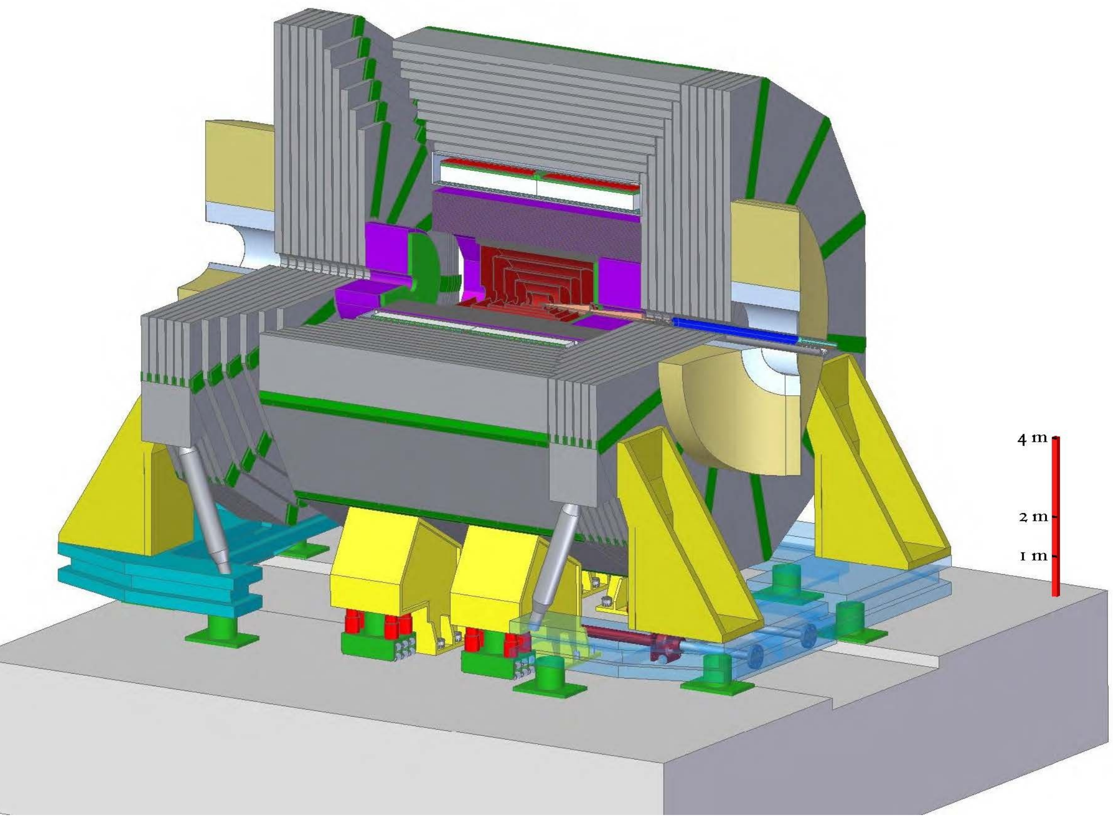
$\sigma_{pT} / p_T^2 \sim 2\text{x}10^{-5} \oplus 1\text{x}10^{-3} / (p_T \sin\theta)\ \text{GeV}^{-1}$

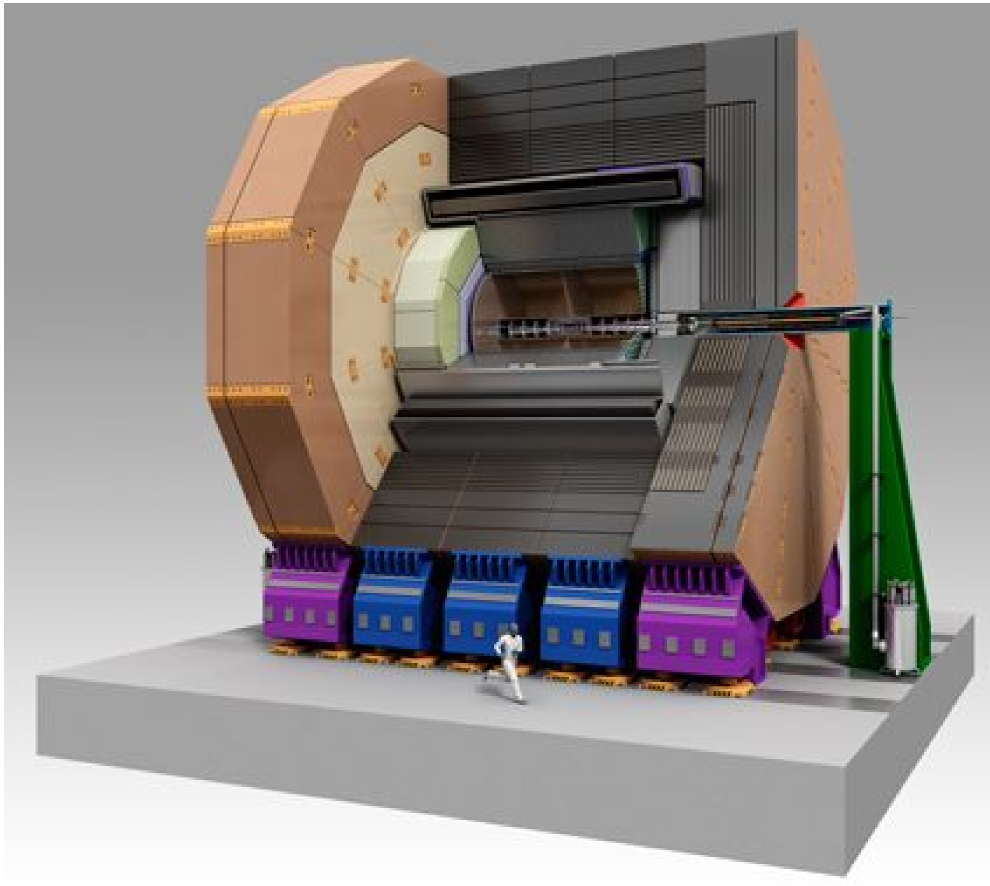
impact parameter resolution

$\sigma_{d0} \sim 5 \oplus 10 / (p \sin^{3/2}\theta)\ \mu\text{m}$

jet energy resolution

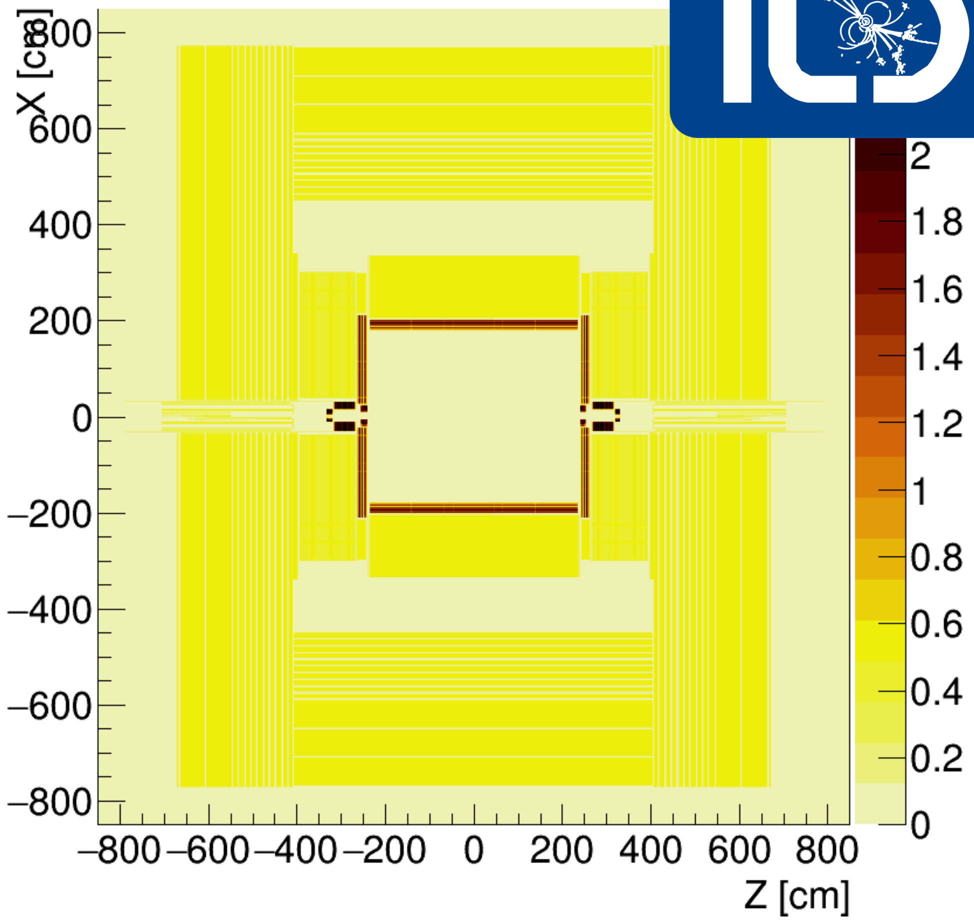
$\sigma_E / E \sim 3 \rightarrow 5\ \%$


4 m
2 m
1 m



	SiD	ILD
Vertex detector:	silicon pixels	
	5 layers	3 double-layers
	r_{in} ~ 13 mm	16 mm
Main tracker:	silicon strips (pixels)	Time Projection Chamber + si strips/pixels
	r_{out} ~ 1.22 m	1.78 m
E-cal:	silicon-tungsten	silicon-tungsten scintillator-tungsten
H-cal:	scintillator-steel	scintillator-steel RPC-steel
B-field	5 T	3.5 T

ILD and SiD detectors described using DD4hep

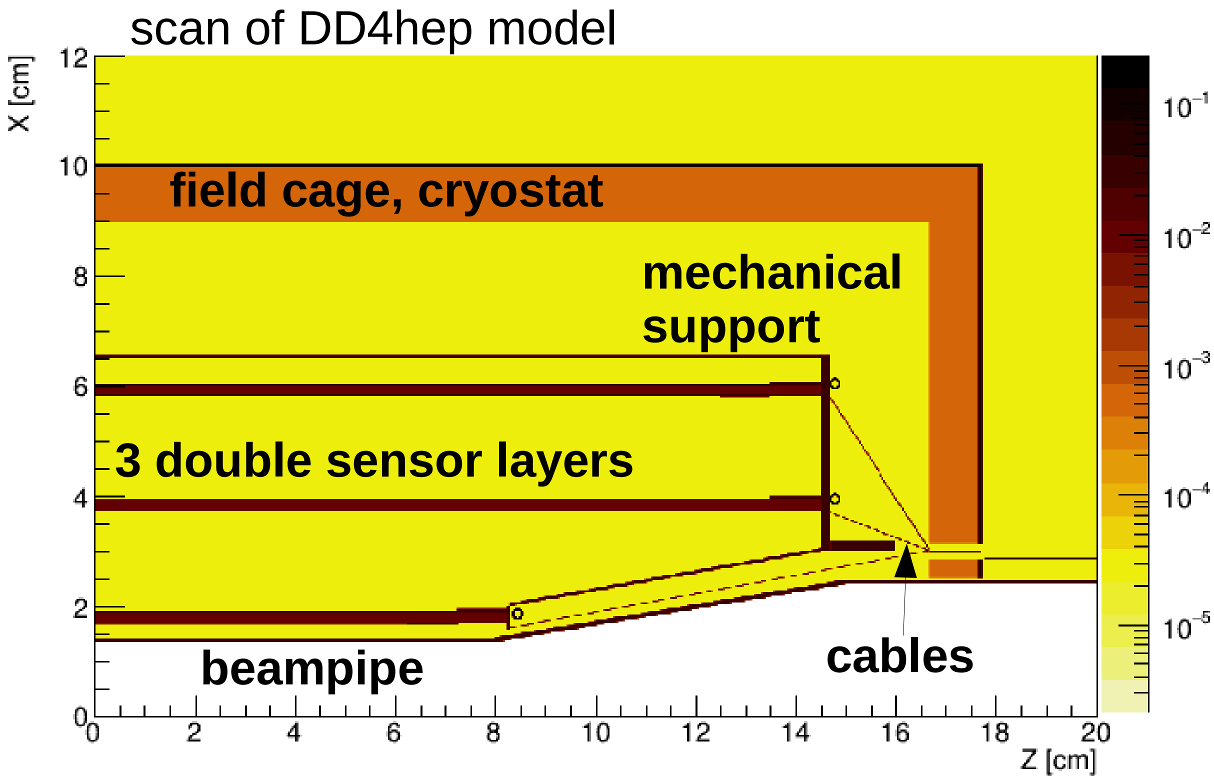


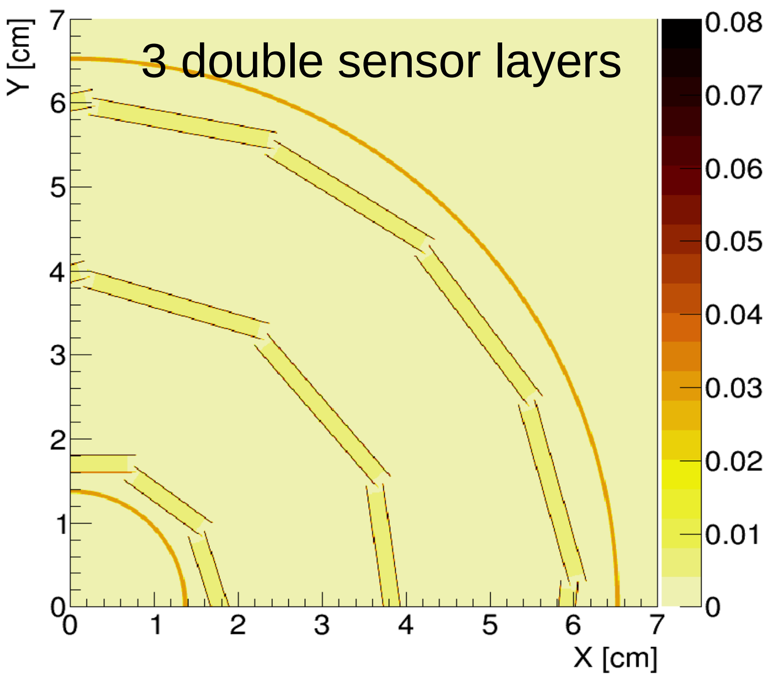
collection of subdetector drivers,
with somewhat scalable dimensions
full detector models defined in compact xml description

vertex detector

essential to achieve resolution goals:
- single hit resolution (~3 μm) and
- low material budget (0.15% X_0/layer)

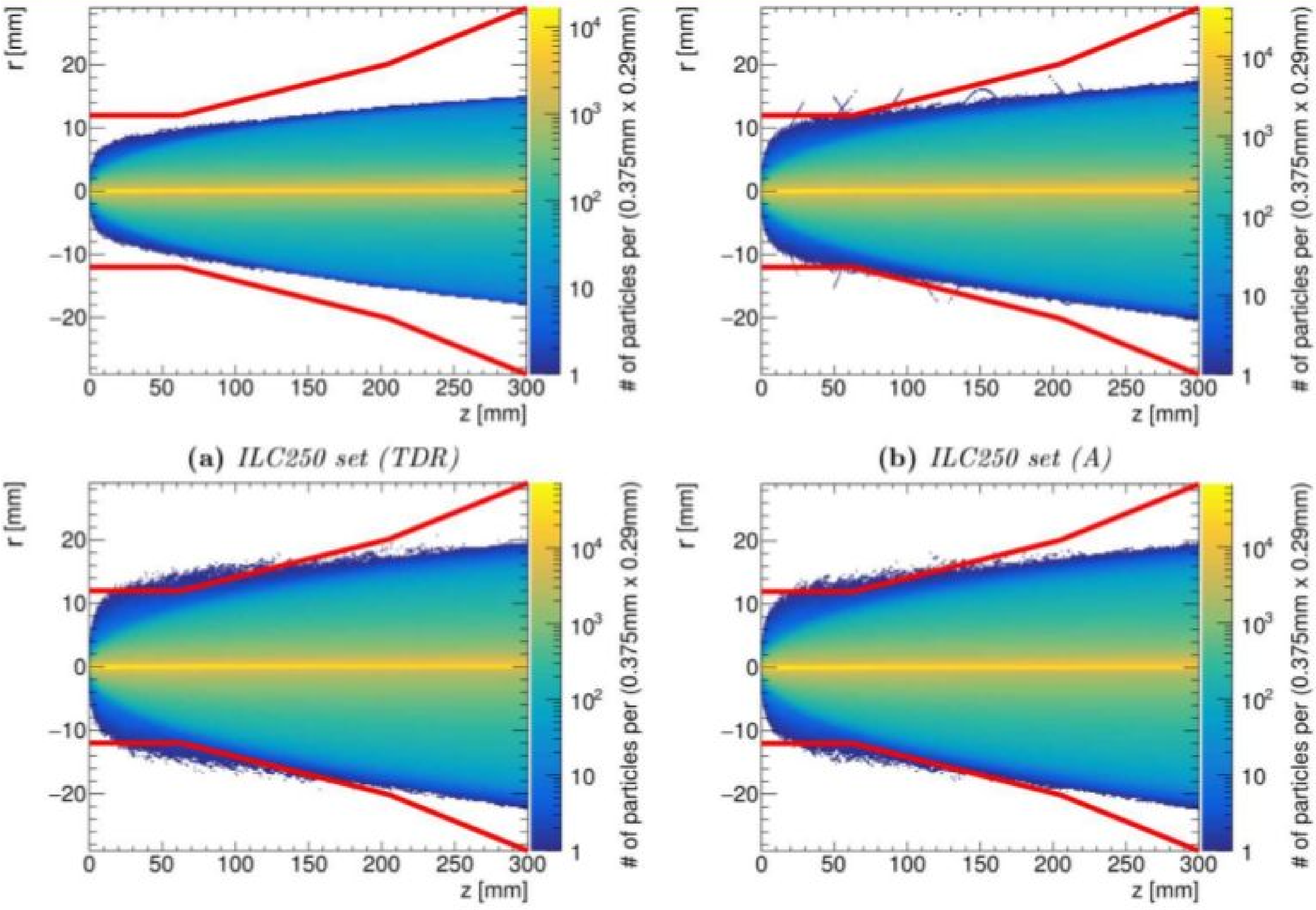
several technological options considered:
- stay somewhat generic in the model





beam pipe and vertex detector constrained by beam backgrounds

beamstrahlung pairs near IP with different ILC beam parameters:



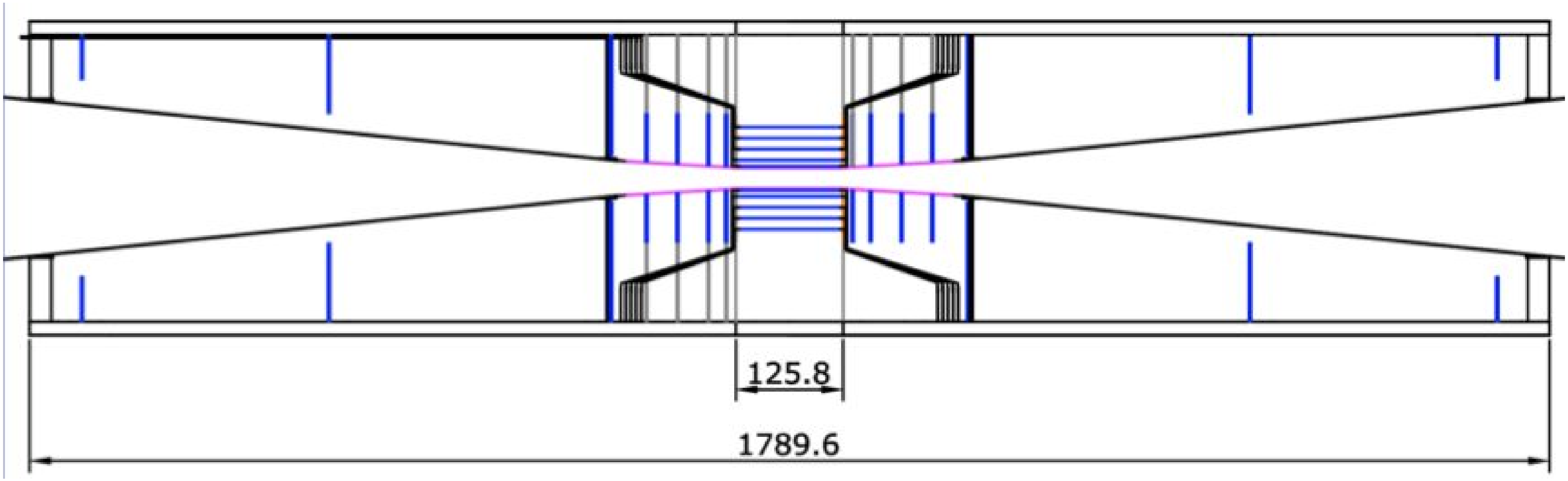
(a) ILC250 set (TDR)

(b) ILC250 set (A)

(c) ILC250 set (B)

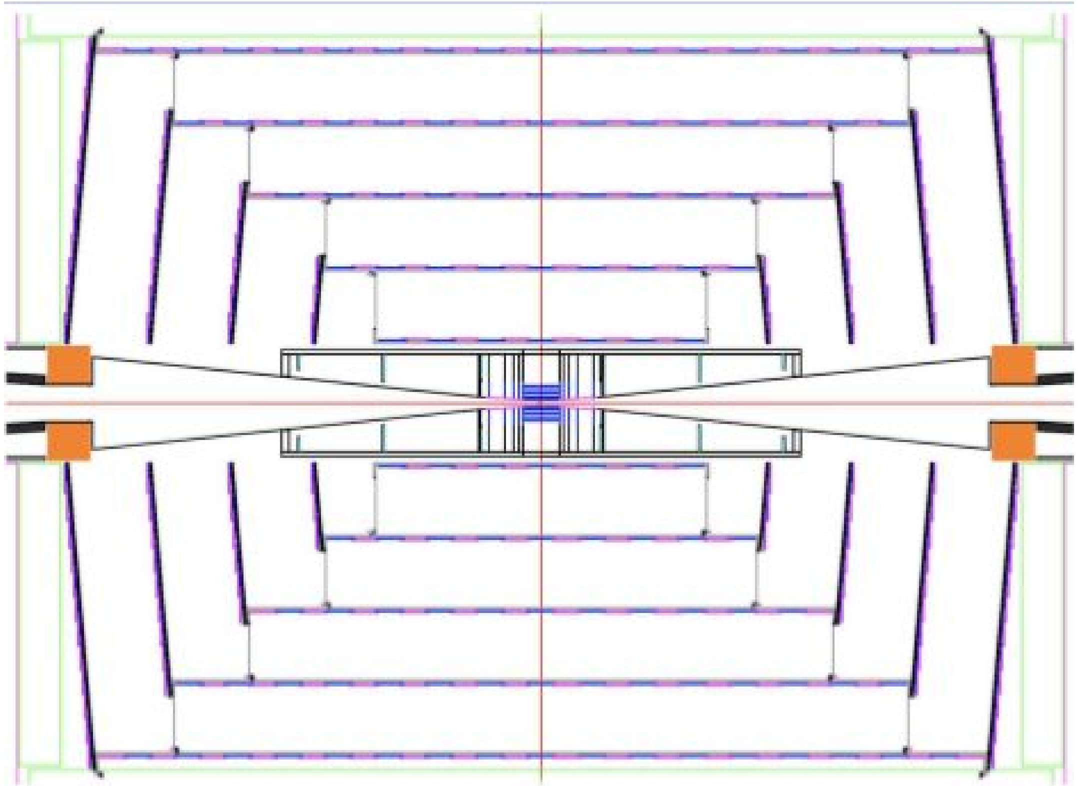
(d) ILC250 set (C)

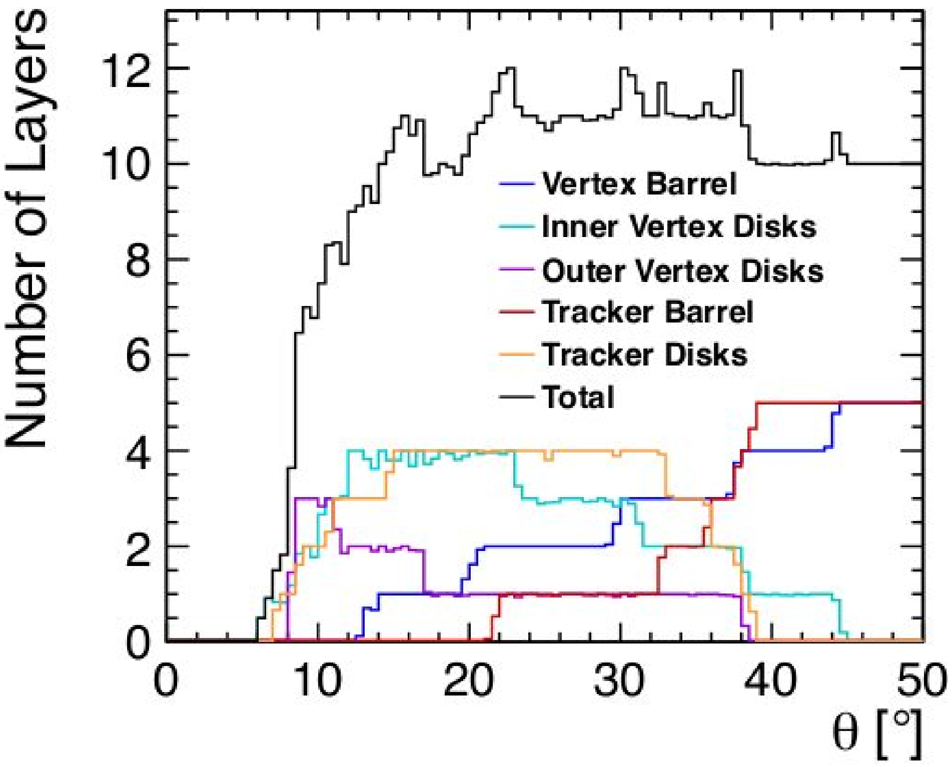
vertex / forward tracker



5 barrel layers, 2 x (4 + 3) forward disks

main tracker





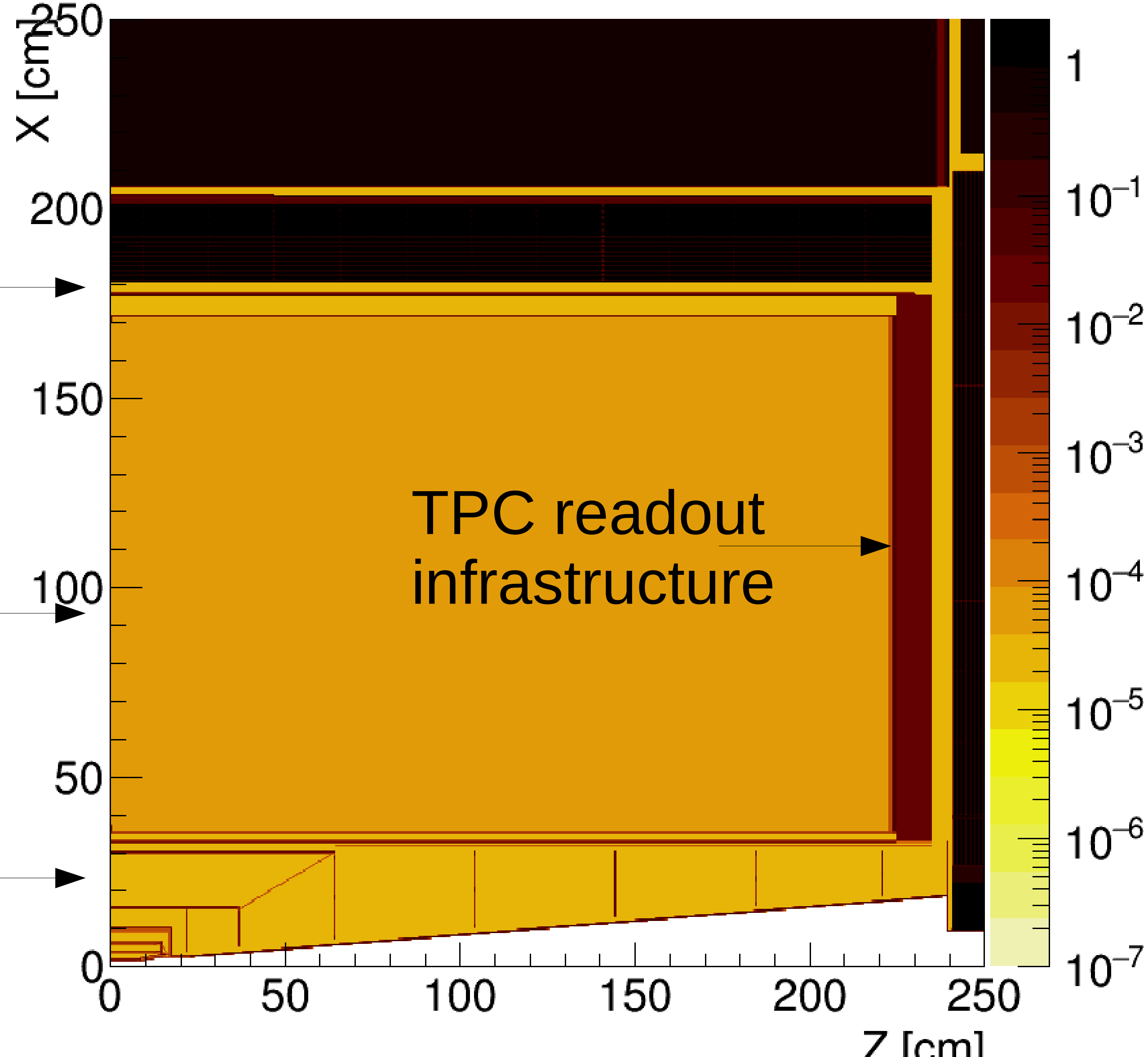
5 barrels of si-strip detectors,
4 conical endcap disks

main tracker

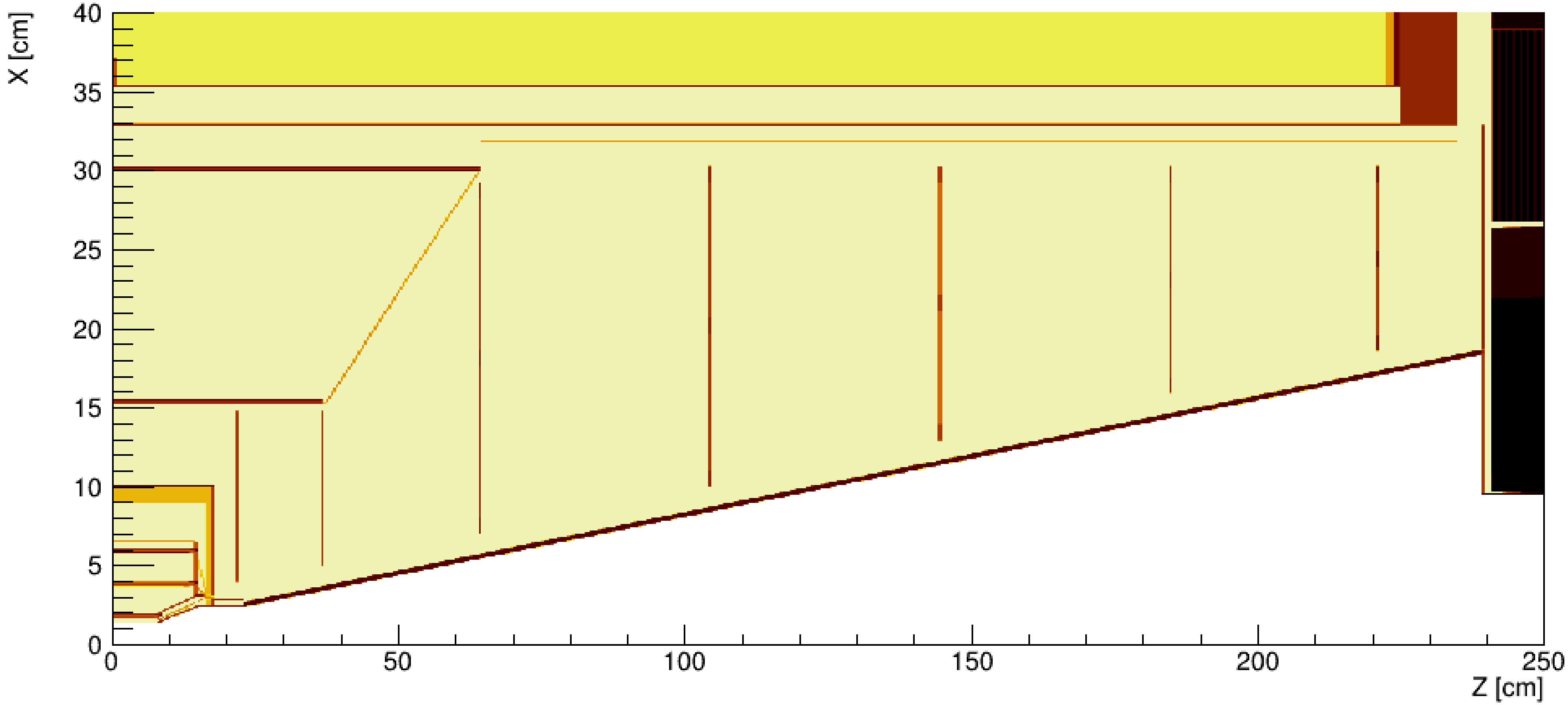
silicon envelope

TPC

inner silicon



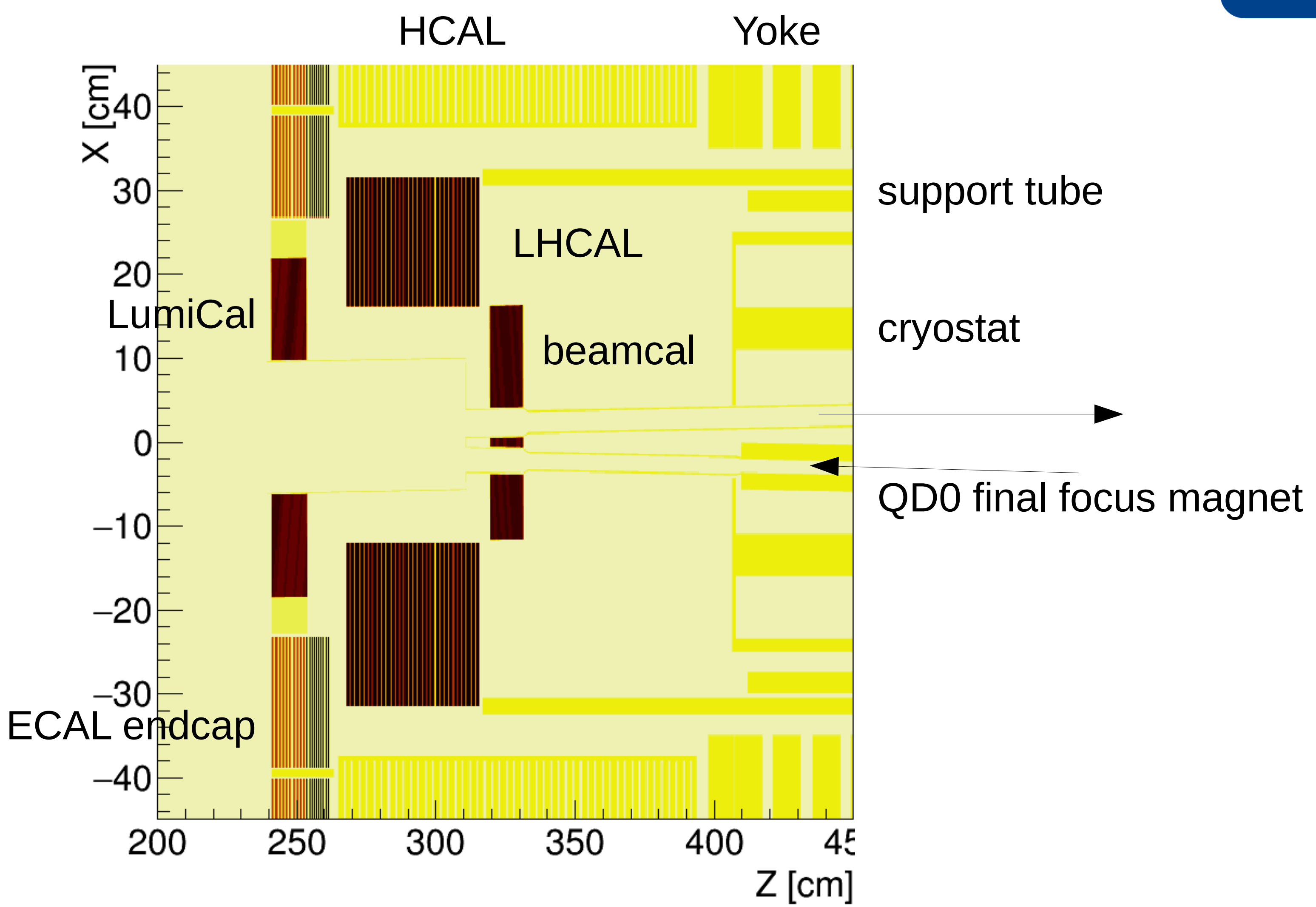
beampipe & forward tracking disks



7 forward tracking disks

cables for inner detectors pass along beampipe:
→ simulation model has thicker walled pipe

Forward region is complex



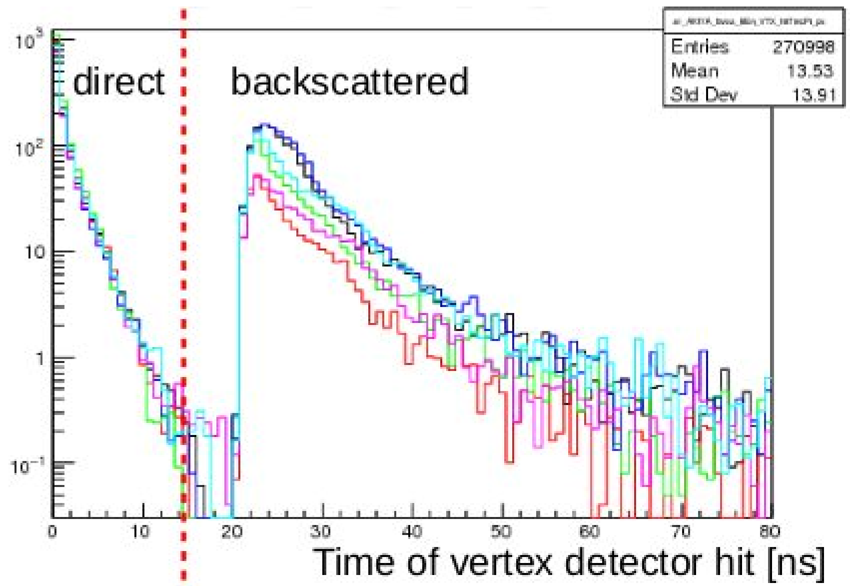
LumiCal → luminosity measurement
BeamCal → beamstrahlung pairs → machine tuning

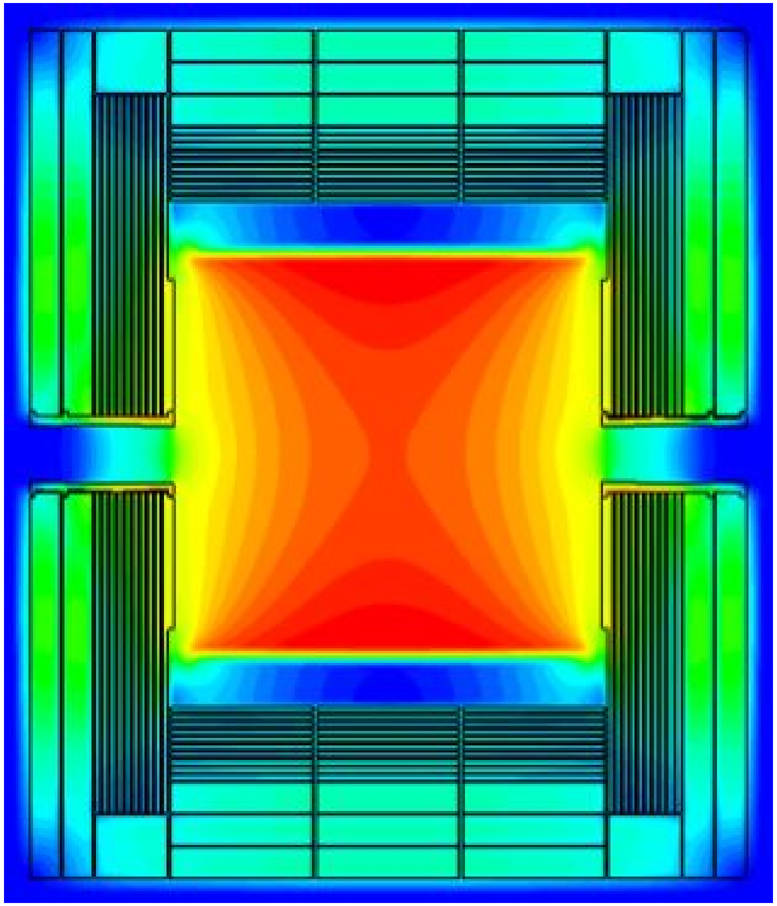
Magnetic field

for general simulations, a uniform solenoid field is assumed

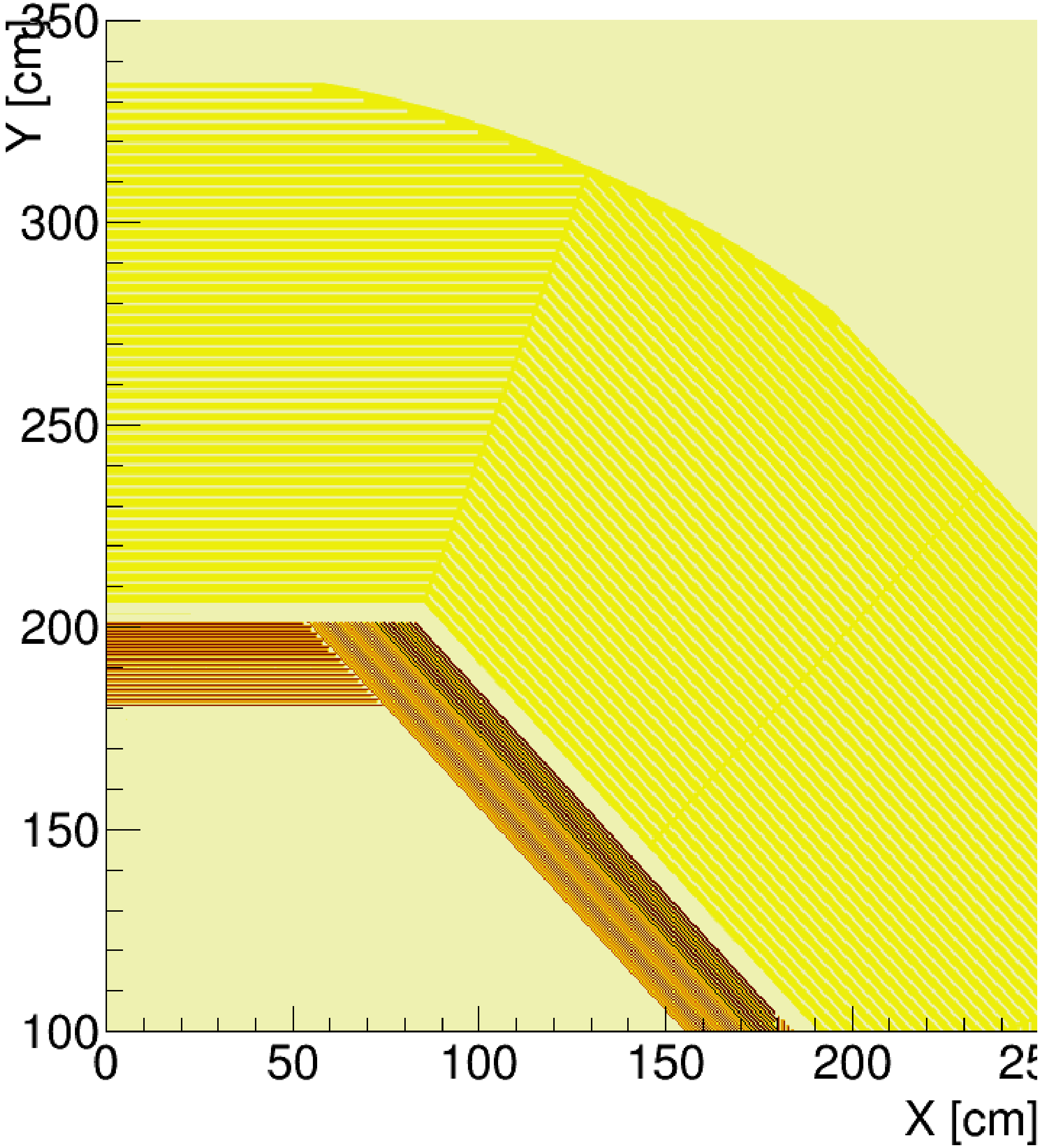
for specific studies: can use
detailed map from field simulations

important for beam-induced pair bg:
low momentum particles,
often reflected from fwd region



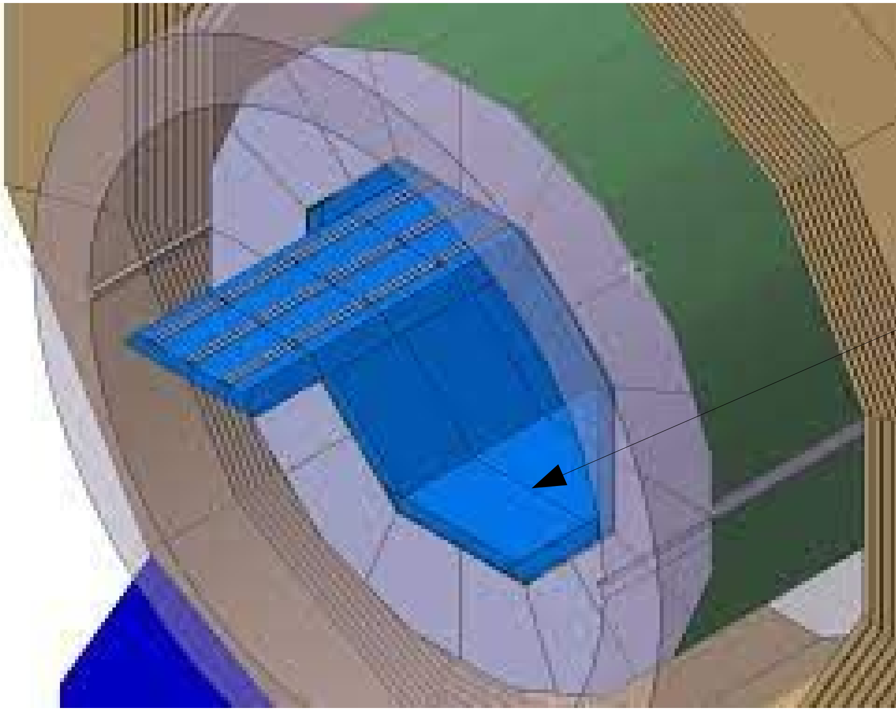


calorimeters



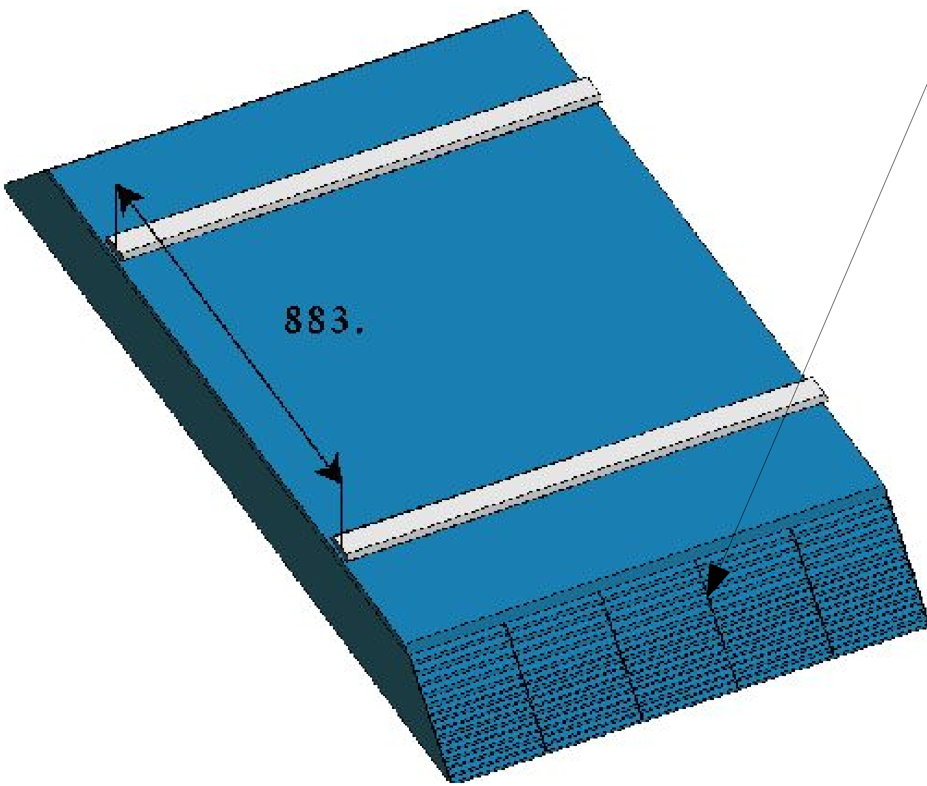
ECAL:
- W + Si
- W + Scint.

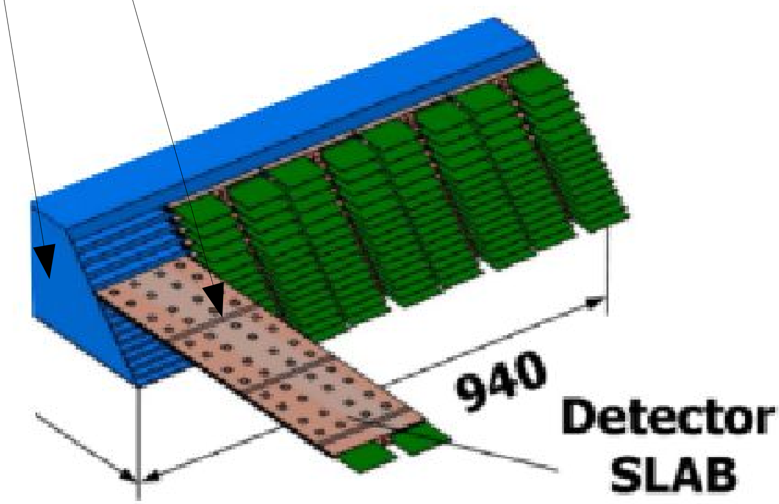
HCAL:
- Fe + Scint.
- Fe + RPC



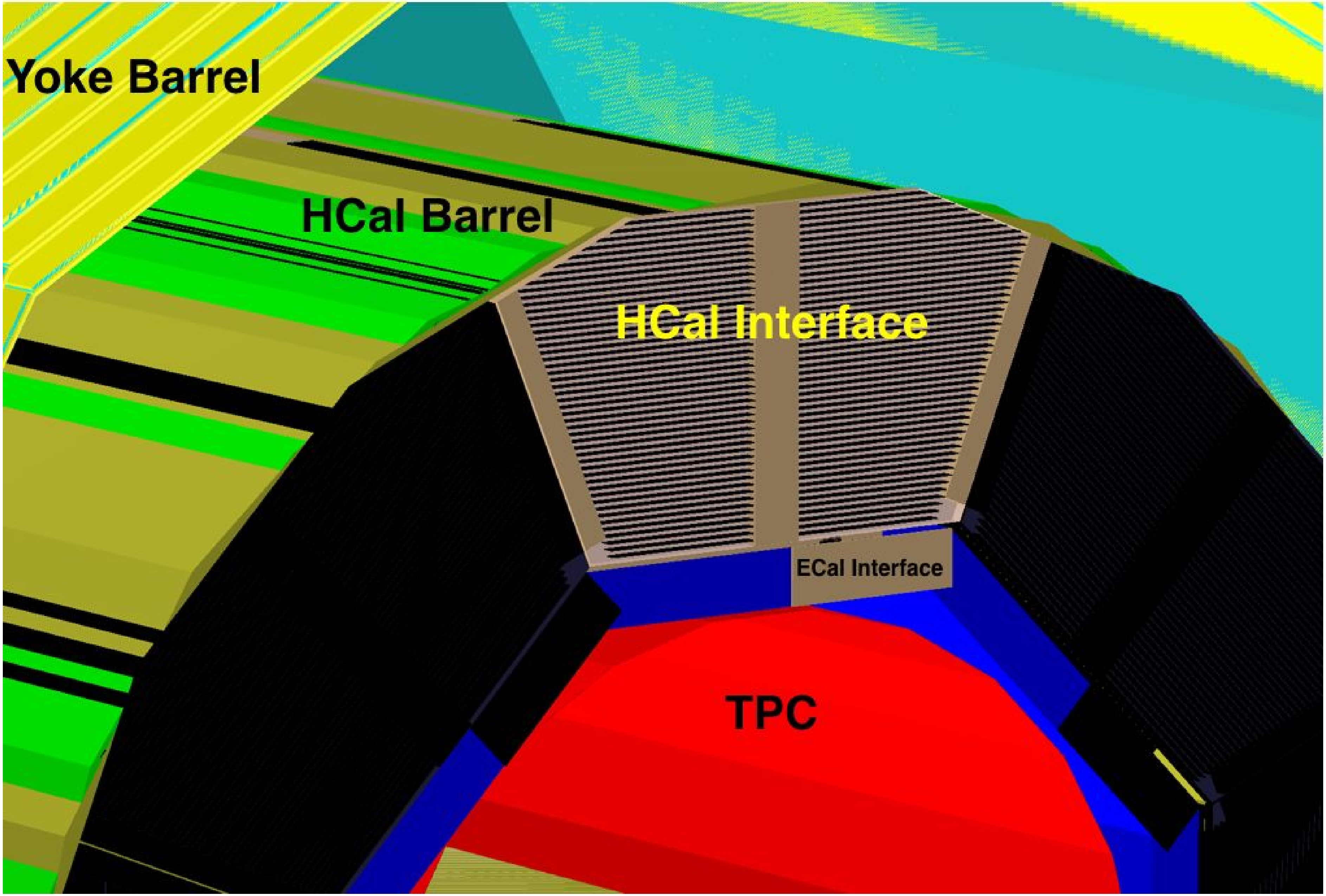
several mm-scale gaps due to ECAL support structures

described in the simulation model



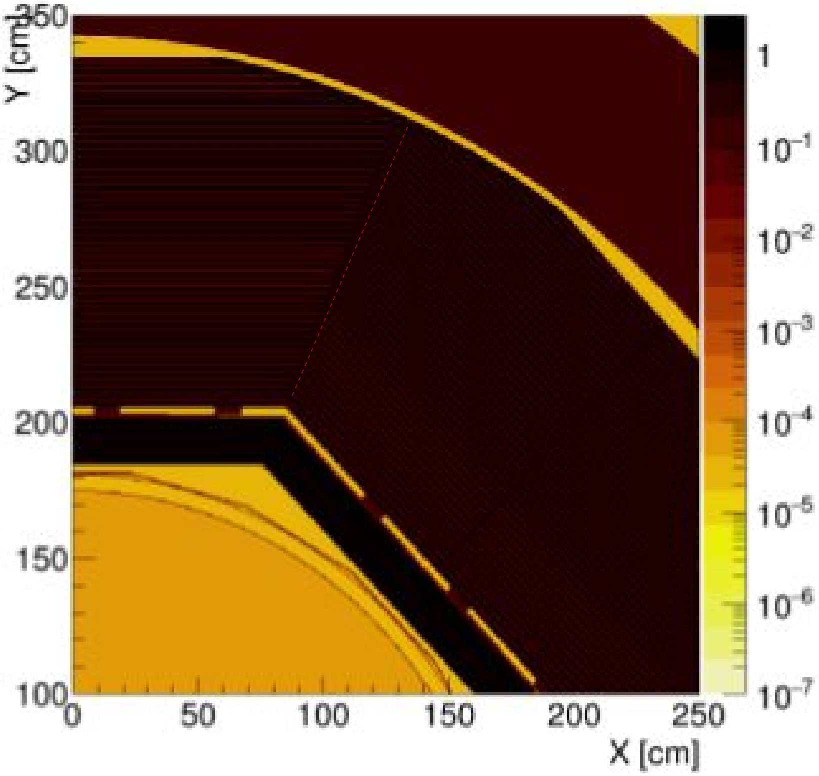


interface boards & services in barrel-endcap gap

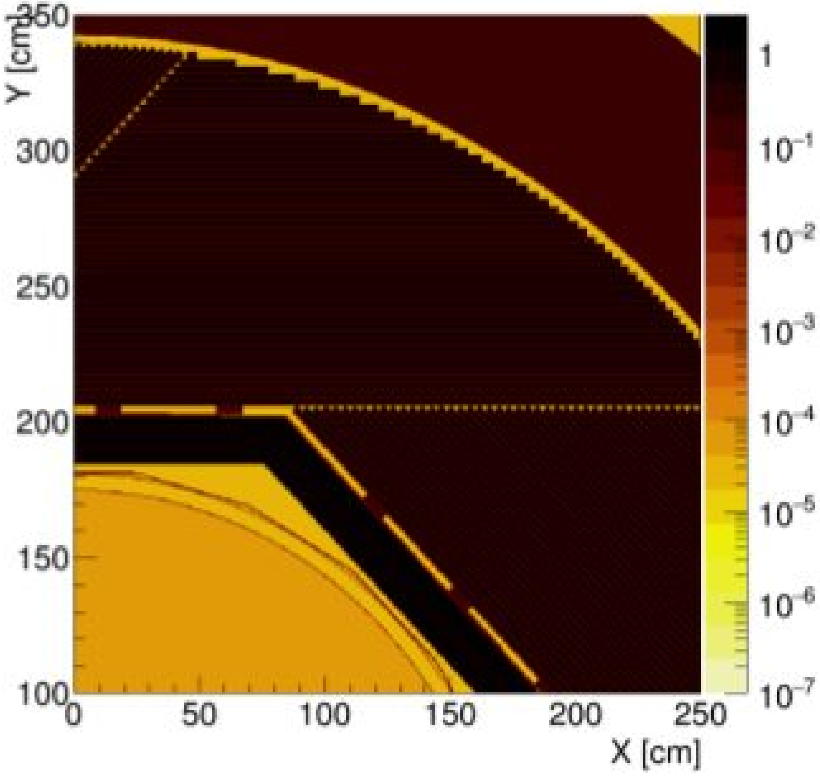


different HCAL geometries

“Tesla”



“Videau”



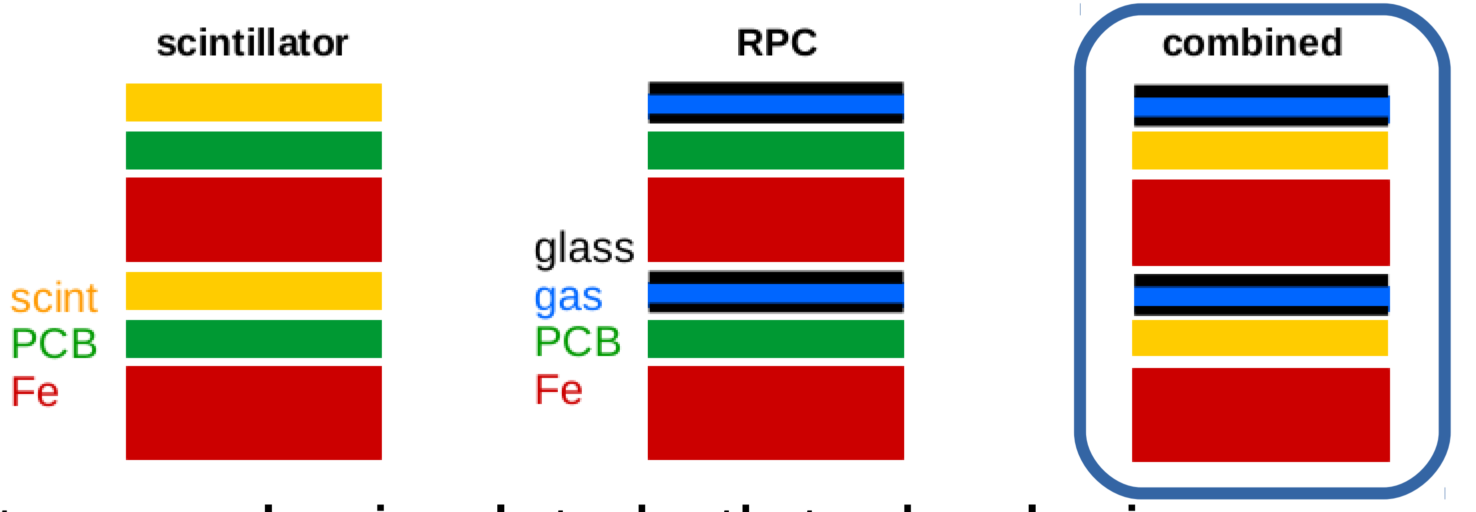
Hybrid calorimeter simulation

ILD considers several technical solutions
for calo implementation

in each HCAL technology, readout layer contains
active detector (scintilator / RPC) + readout PCB
they have similar thickness (both in mm and X_0)

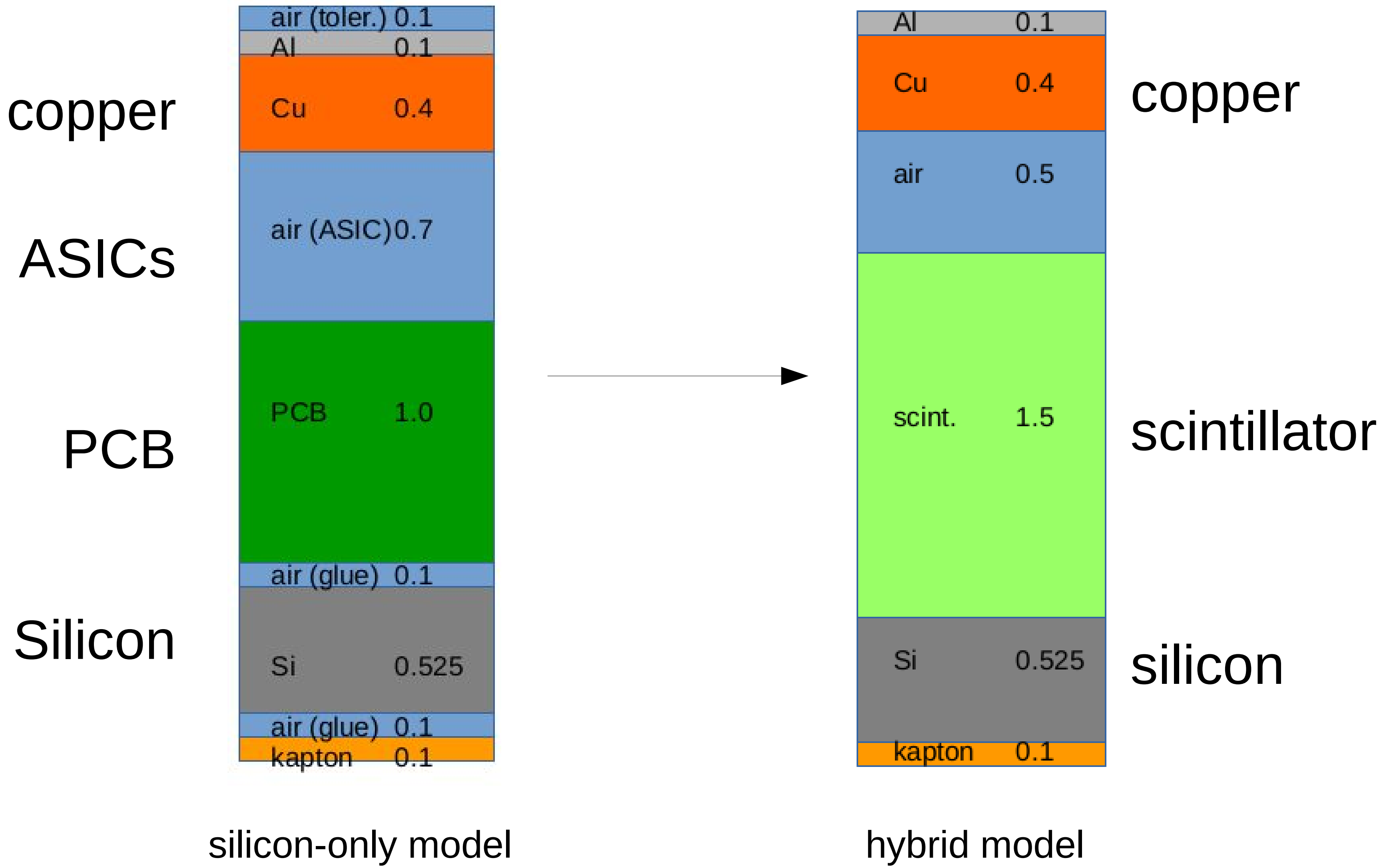
→ define combined model, with both active detectors (and no PCB)

(simplified)



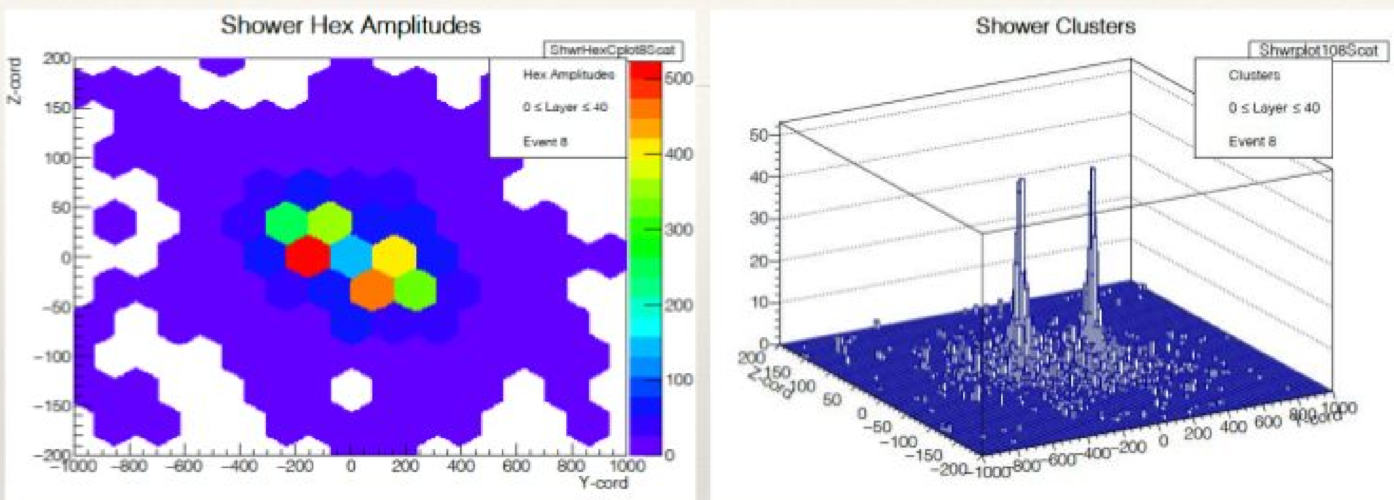
→ simultaneously simulate both technologies,
independent collections of hits
choose which one to use at reconstruction time

similar hybrid approach in ECAL simulation



studies of MAPS-based ECAL

can provide far superior 2-shower separation



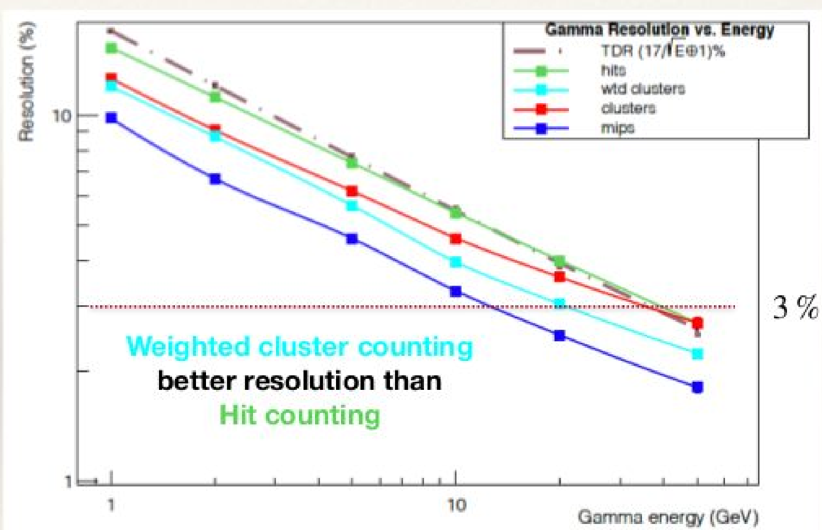
SiD TDR hexagonal sensors
13 mm^2 pixels

New SiD fine pixel sensors
25 μm x 100 μm pixels

Resolution vs. Energy (hits/ clusters/ mips

Simple cluster performance is better than hit counting.

When clusters are weighted by properties (size & cluster location) the performance improves.



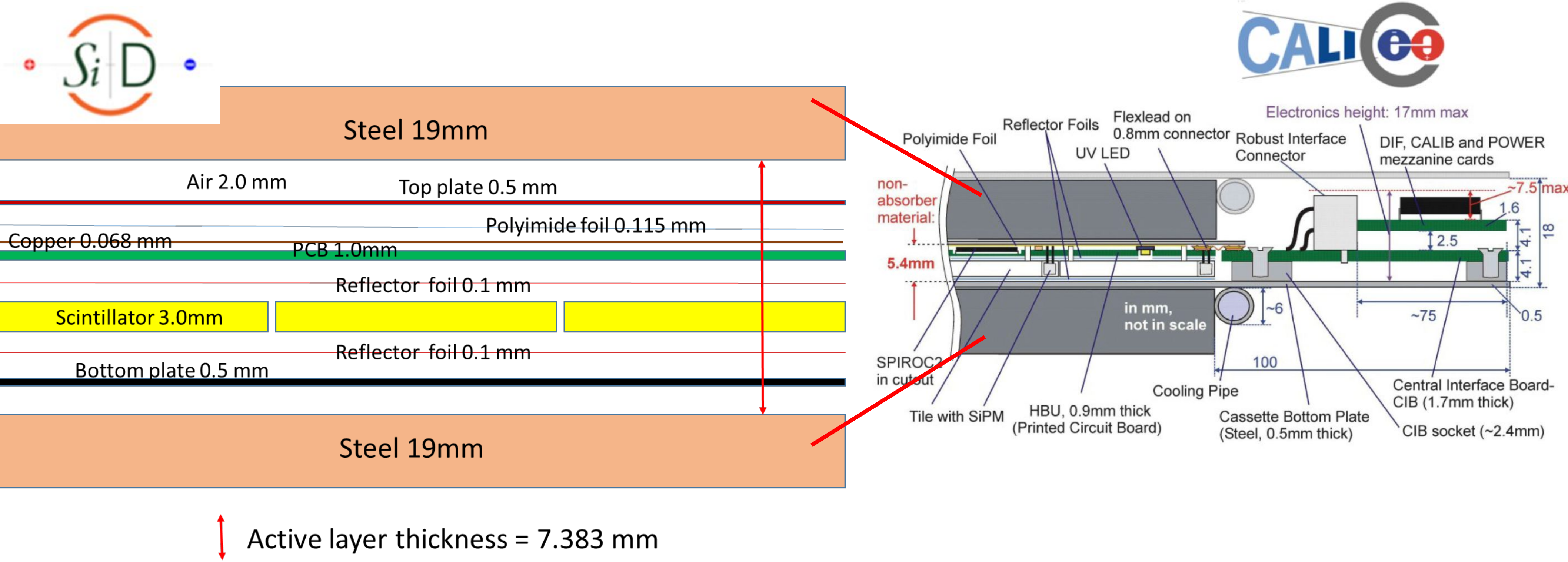
3 %

also somewhat improved energy resolution

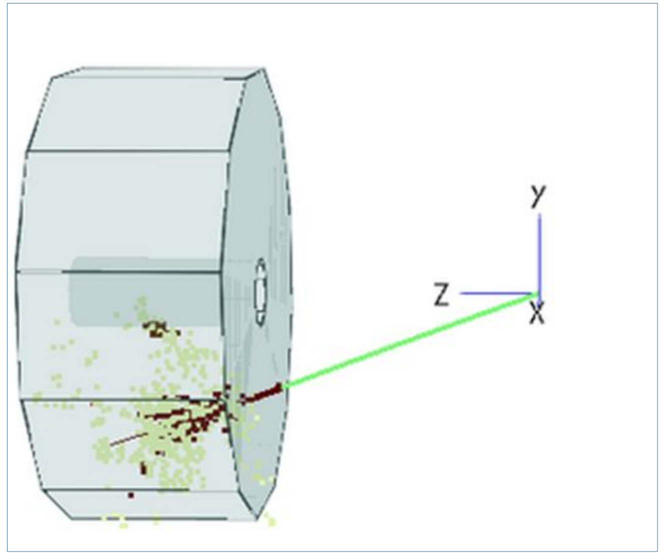
studies performed in standalone G4 simulation close contact with sub-detector R&D groups

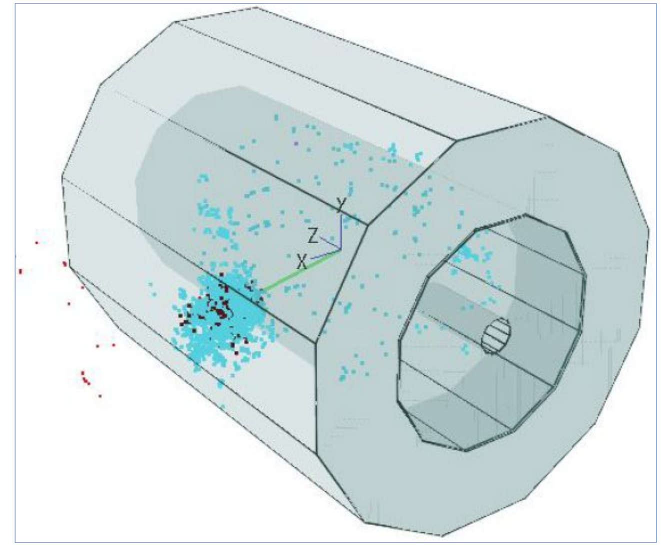
→ realistic simulation model

e.g. SiD ↔ CALICE Hadron Calorimeter

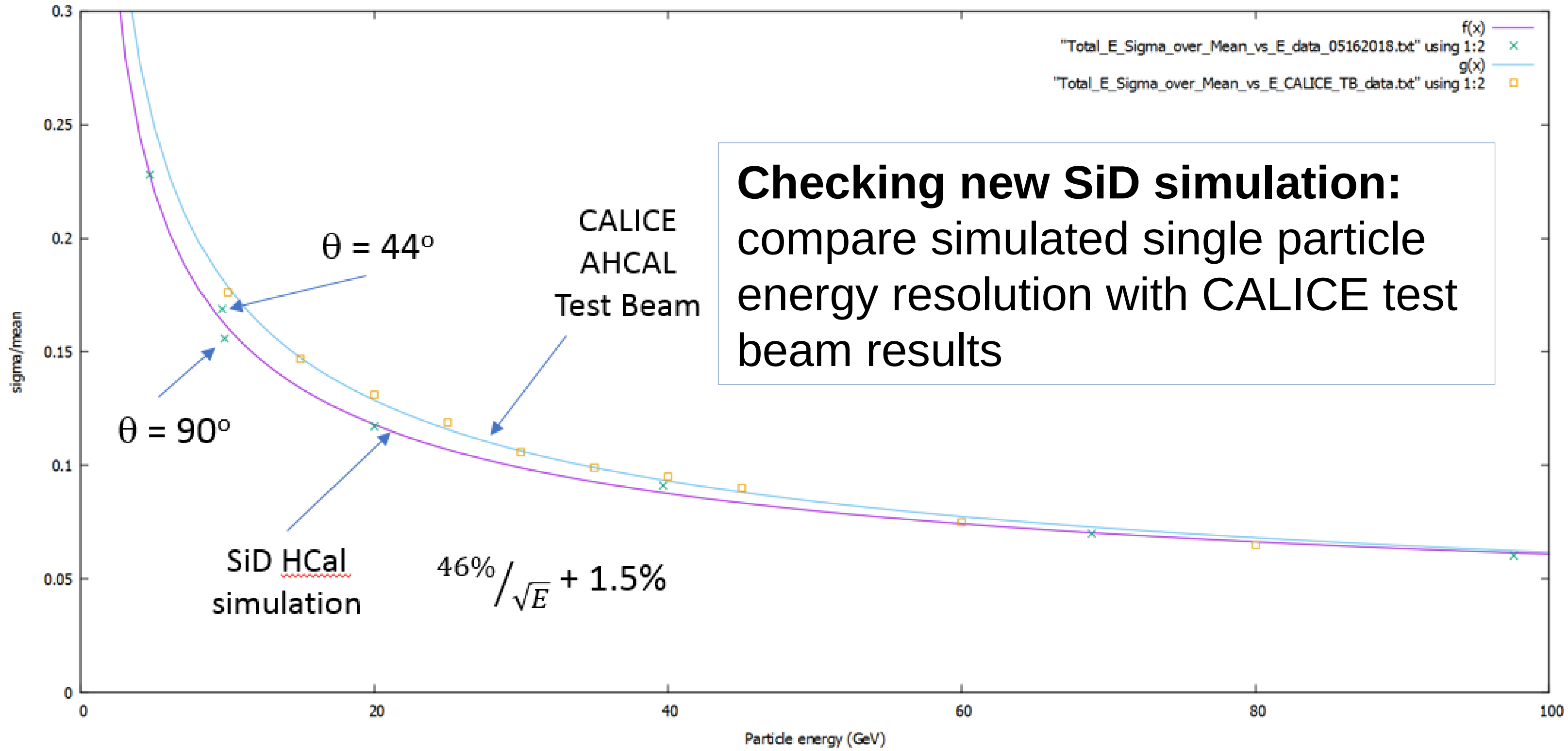


→ also most appropriate G4 physics lists



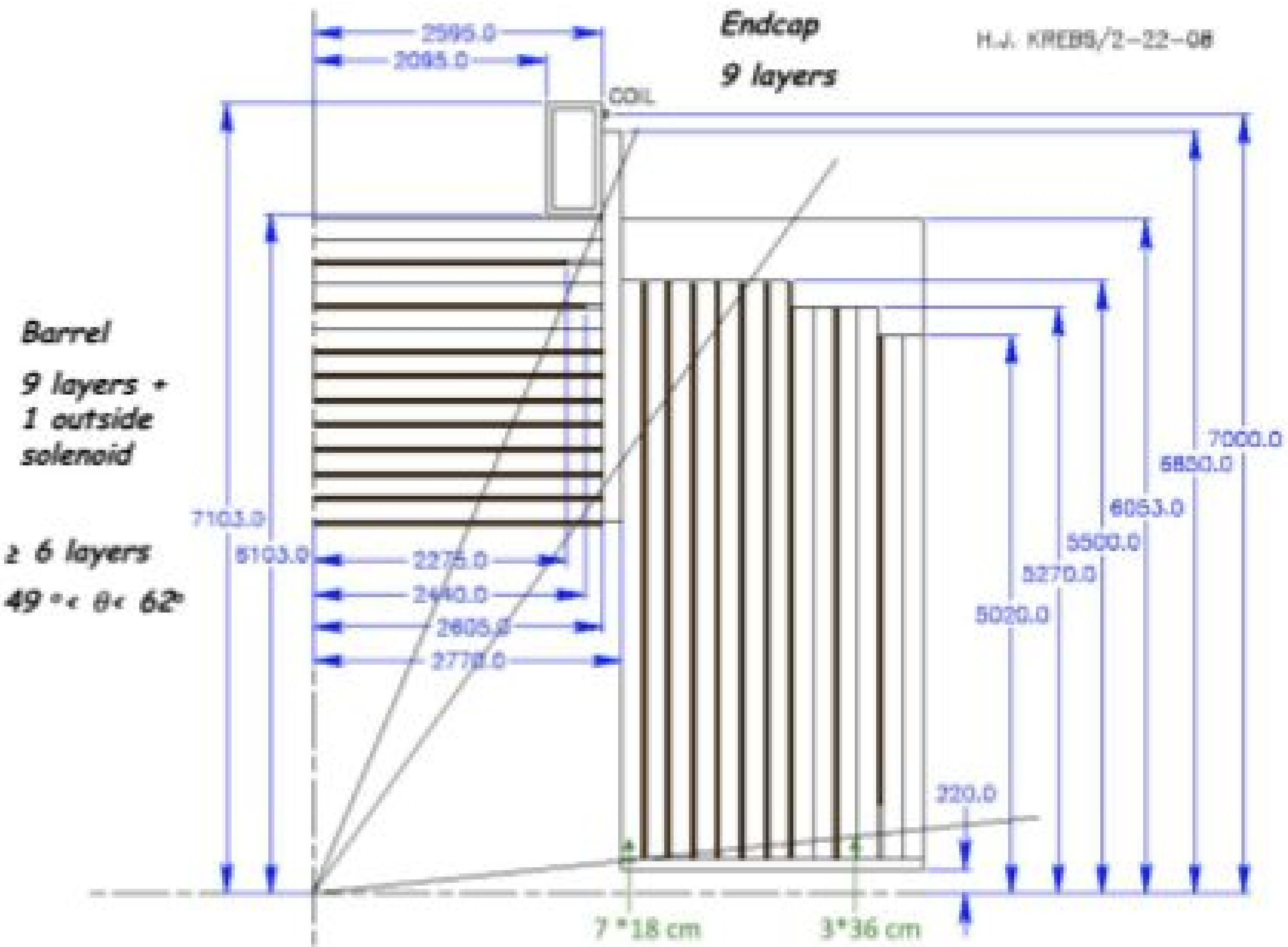


Checking new SiD simulation: compare simulated single particle energy resolution with CALICE test beam results



A. Myers, AW - UTA

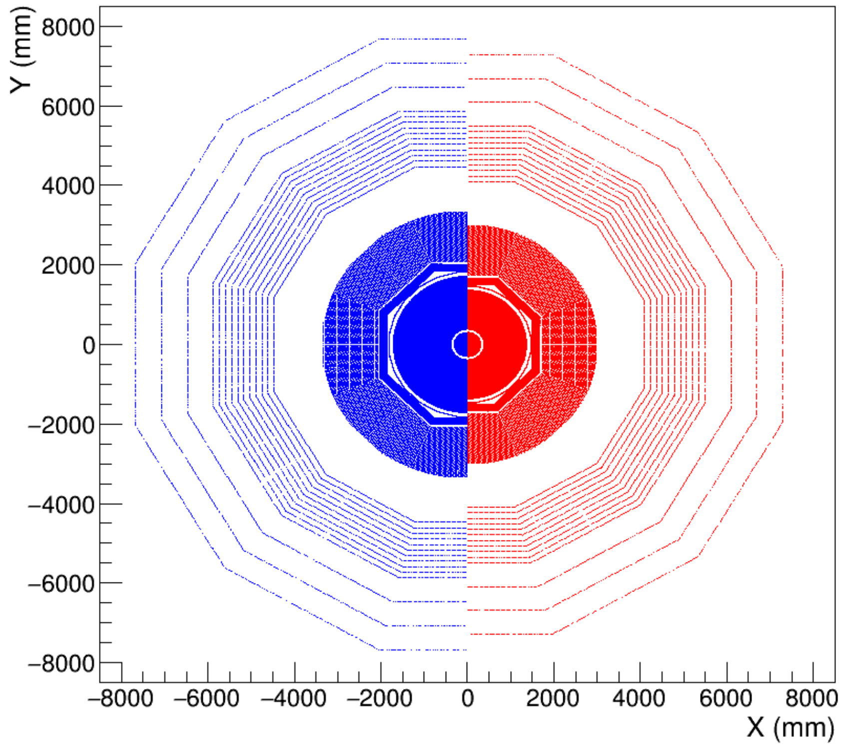
muon detector system / yoke instrumentation

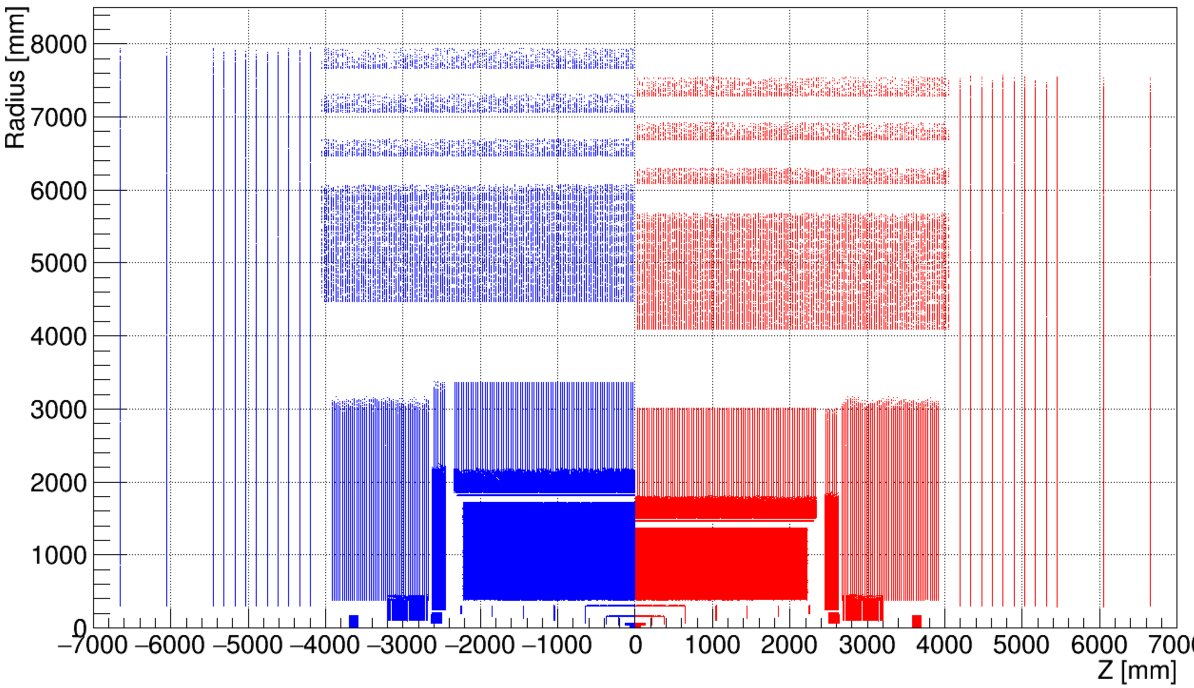


steel + scintillator

at high energies, also use as calorimeter tail-catcher

Large / Small ILD versions





relatively easy due to scalable geometry description

recently prepared full set of physics samples @ 500 GeV
→ extensive optimisation study with many physics studies

ddsim used to run simulations

DDG4 used to interface geometry models to Geant4

→ sensitive layers and segmentation

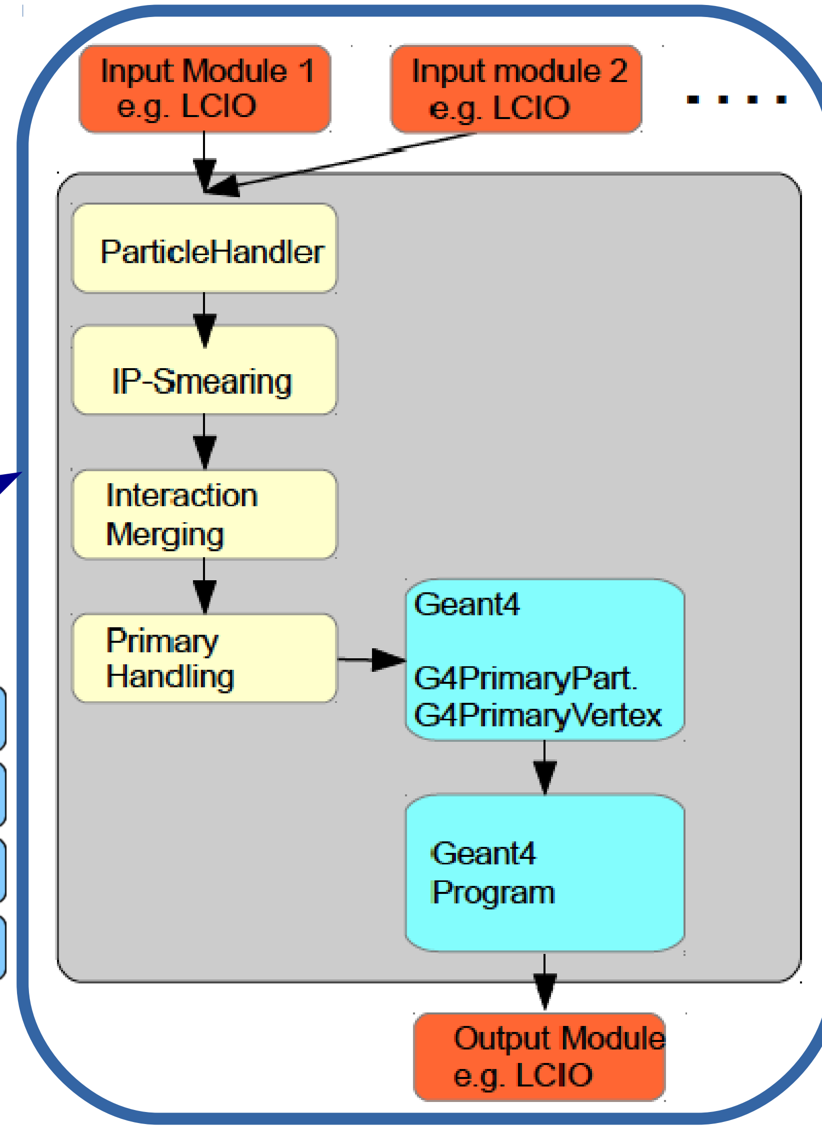
→ detailed information about steps/hits

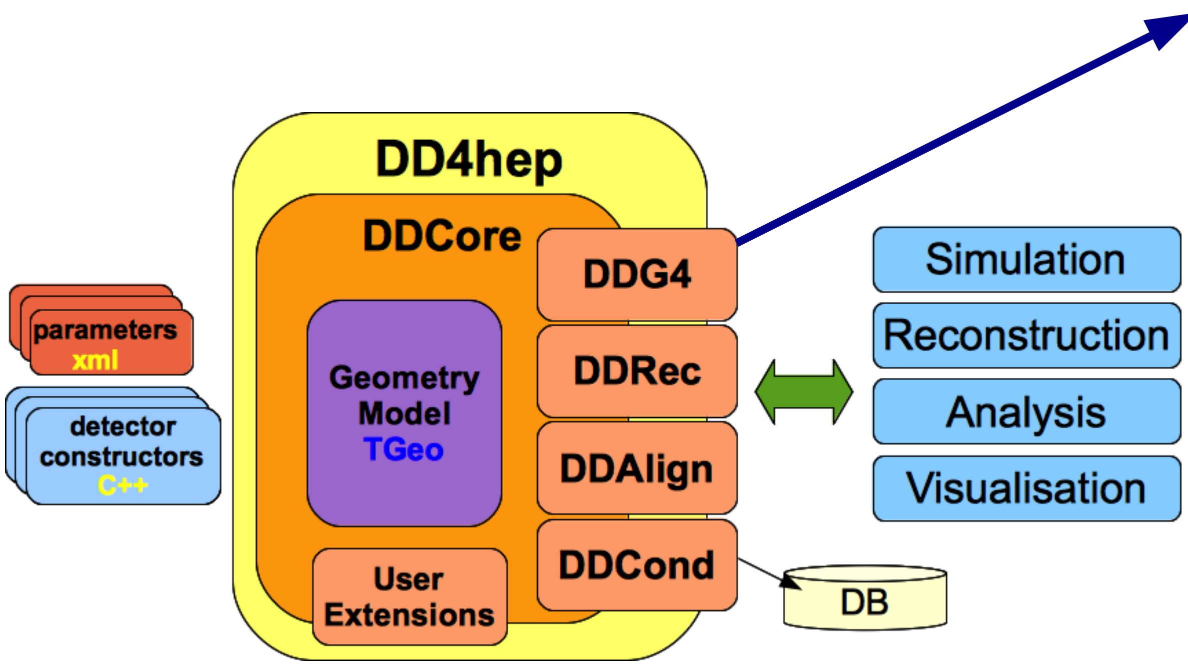
→ linking between hits and the MCParticles which produced them

→ Geant4 configuration

physics lists, regions, range cuts

→ input / output lcio, will move to EDM4hep





after Geant4 modeling,

- have list of energy deposits in sensitive detectors,
  - their time, position, cellID, ...

hit digitisation → realistic detector response

- technology dependent
  - smearing of hit position, energy, time
  - e.g. ongoing studies on timing in calorimeter

only then ready to pass on to

- reconstruction algorithms and physics analysis !

Summary

- huge effort in producing detailed simulation models
for ILC detectors SiD & ILD

- important to ensure close contact between
hardware and software experts when developing models
→ benchmark performance against prototypes

- modular and scalar geometrical models
→ easier to adjust global parameters
→ switch in and out different options

- rely heavily on software tools DD4hep, DDG4,
to connect to Geant4