An ECAL for the DUNE ND

High-level Intro

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DEEP UNDERGROUND NEUTRINO EXPERIMENT

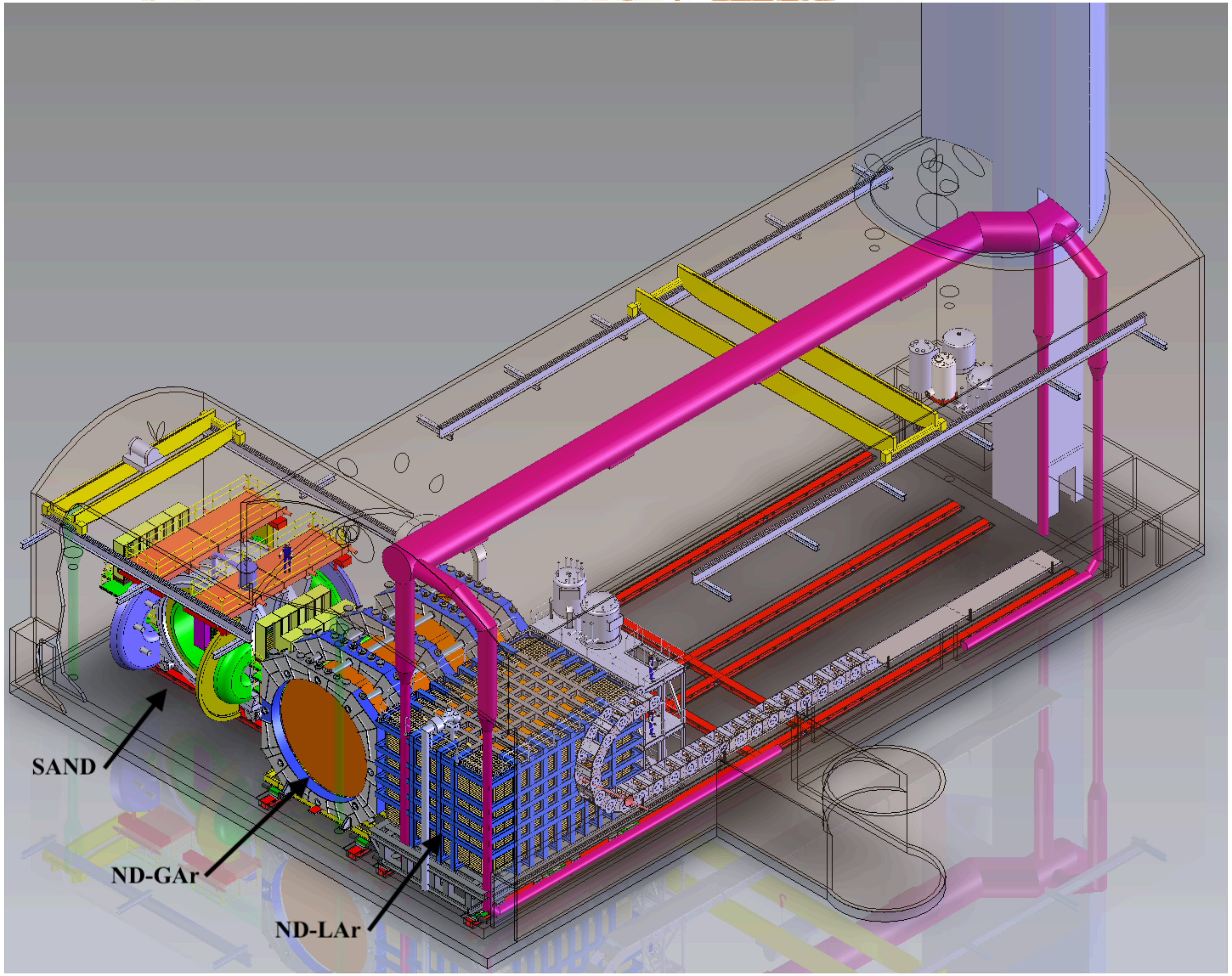
DE-F DUNE ND Meeting

Zoom, October 2020

MAX-PLANCK-INSTITUT FÜR PHYSIK

The DUNE ND Complex

Three separate detectors



- A **liquid Ar TPC ND-LAr** with short drift length and pixelated readout
- A **Multi-Purpose Detector ND-GAr** with HPgTPC tracking + ECAL in a magnetic field
- An **on-axis beam monitor SAND** with tracking target (scintillator and / or gas), calorimetry and magnetic field

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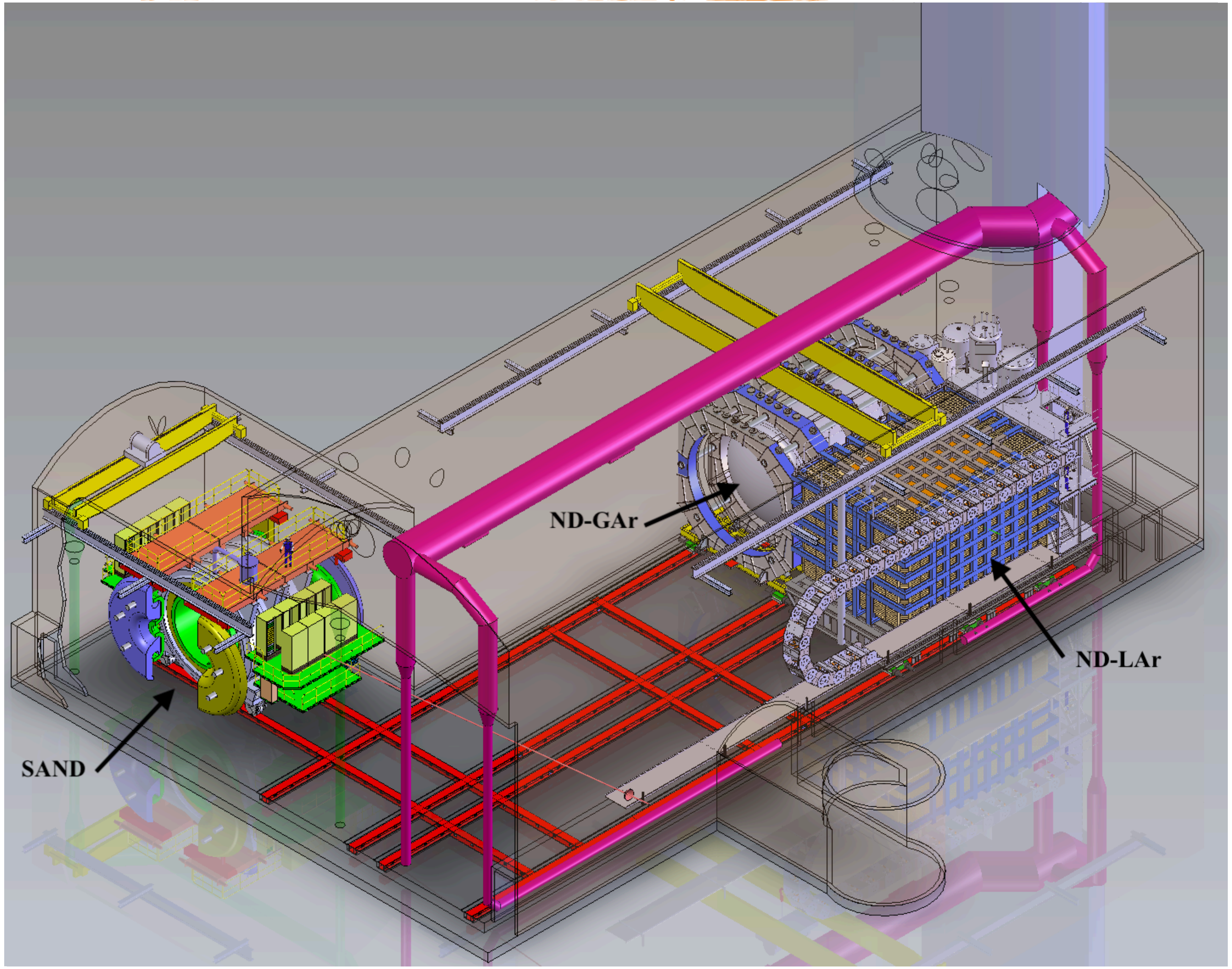

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- ND-LAr and ND-GAr can move off-axis to measure at different energies / ν spectra: **DUNE-PRISM**
  - break cross section model degeneracies
  - linearly combine off-axis samples to construct arbitrary spectra: build FD-like oscillated spectra - reduction of model dependence

MPD ECAL - Overall Concept

Motivation & Goals

- The MPD will make high-precision measurements of ν interactions on Ar
  - Requires full coverage and precise measurement of charged and neutral particles with low thresholds

- ECAL and HPgTPC complementing each other
  The ***ECAL*** has to provide:
  - Photon energy measurement
  - Neutral pion reconstruction
  - Particle identification (electron, muon, pion)
  - Determination of interaction time, muon tracking into and out of TPC
  - Ideally: Neutron detection and energy measurement
  - …

➩ Energy range from ~ 50 MeV to ~ 2 GeV: Small stochastic term crucial

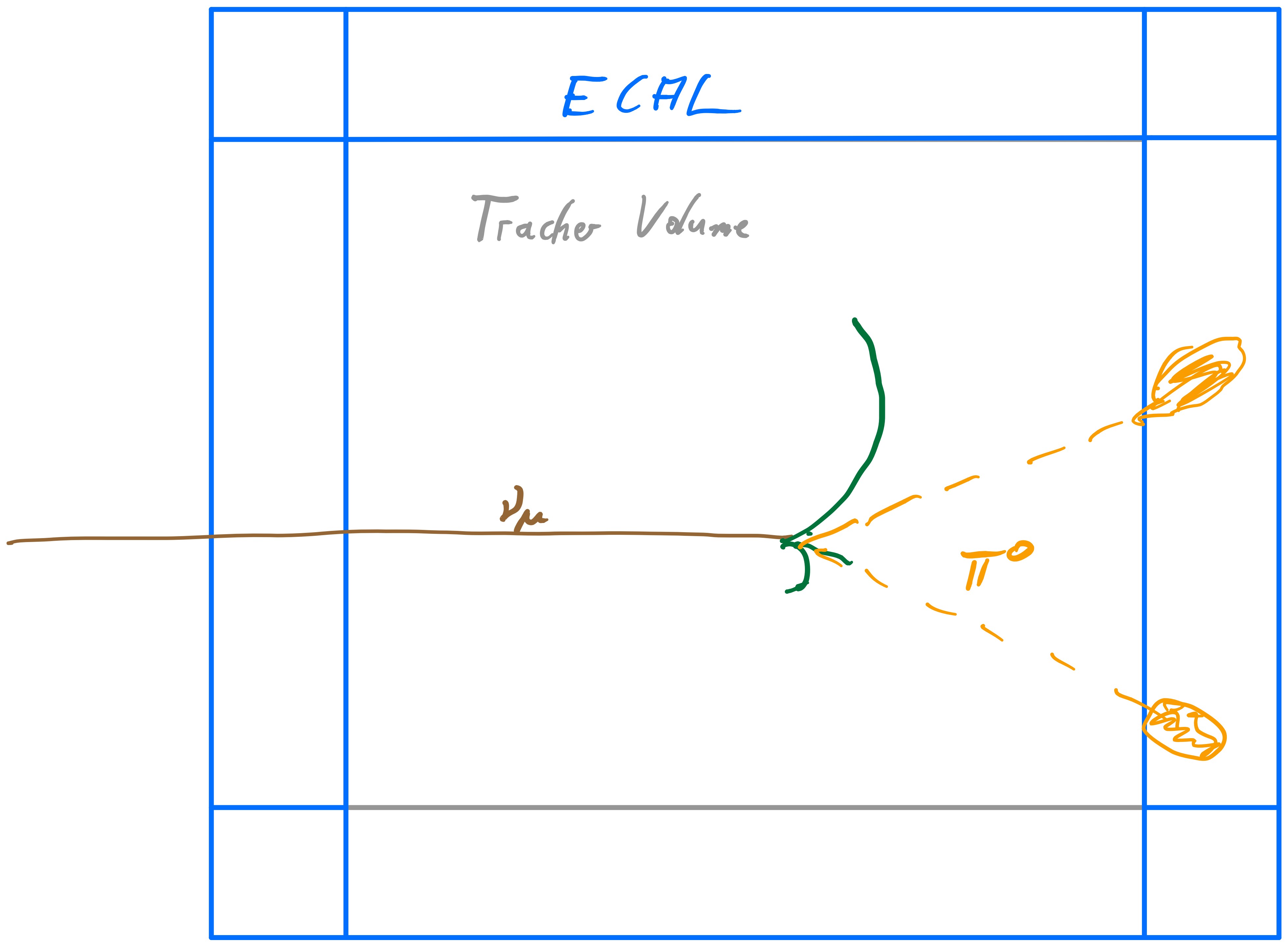
➩ Requires longitudinal segmentation

several 100k interaction/year on Ar in tracker
several 100M interactions/year in ECAL

Main Performance Goals

And consequences for Calorimeter Concept

- Electromagnetic resolution: 6 %- 8% / Sqrt(E [GeV])
  - Drives sampling structure: Thin absorbers!
- π^0 reconstruction: Requires shower separation, position and angular resolution
  - Motivates highly granular readout



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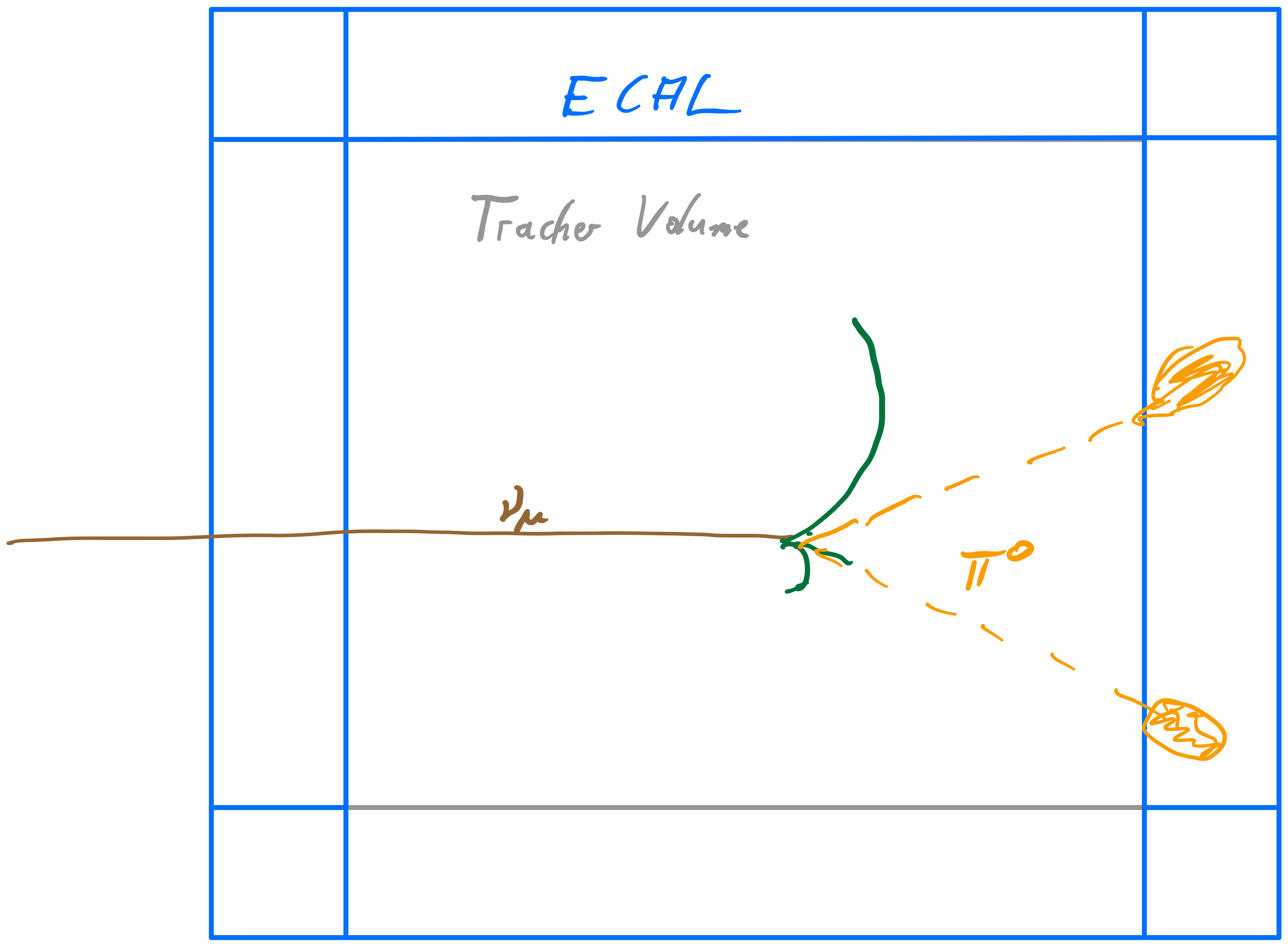
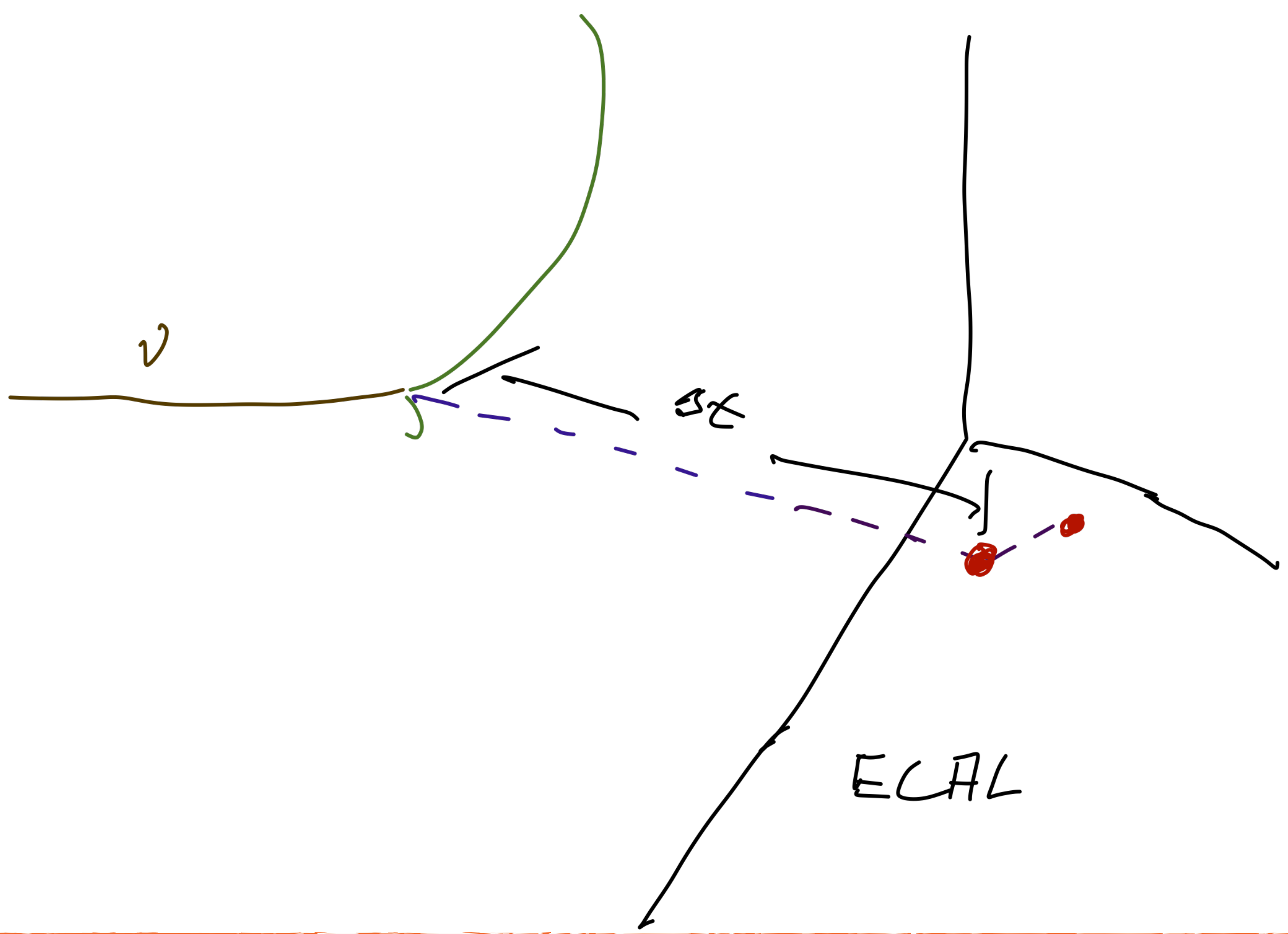


- Neutron reconstruction - a potential game-changer [still needs to be established in realistic environments!]
  - Requires timing on the few 100 ps - 1 ns level to enable energy measurement via time-of-flight

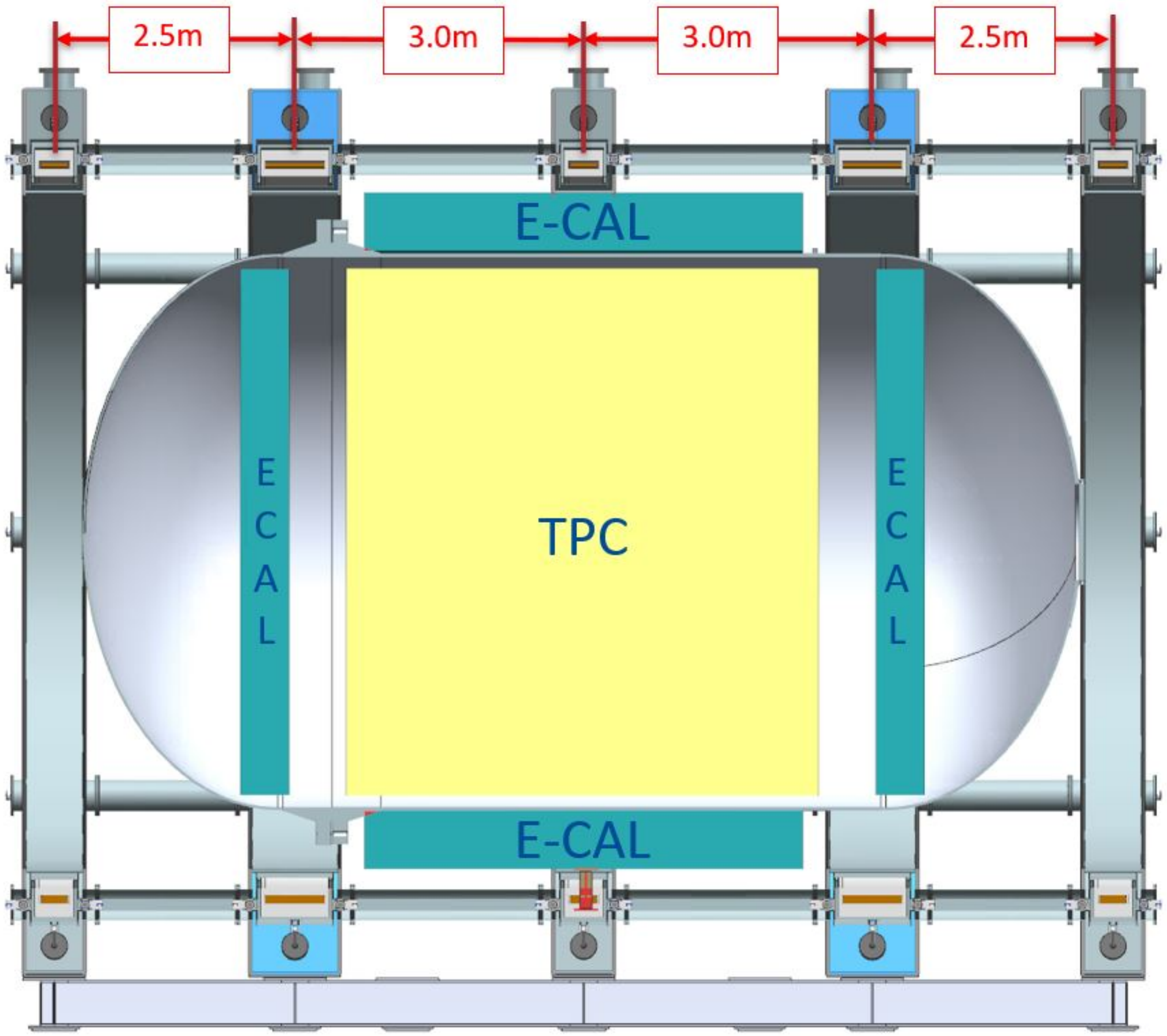


Integration of ECAL with Rest of MPD

Close connection to pressure vessel

- Still in early phase of development
  - Strong correlation with PV design
    - With dome-shaped ends, the PV will get very long: prohibitively large ECAL
    - With flat ends (currently under study), PV ends are too much material: no measurement left
  - ➩ Expect barrel outside PV, endcaps inside: Interesting integration issues!

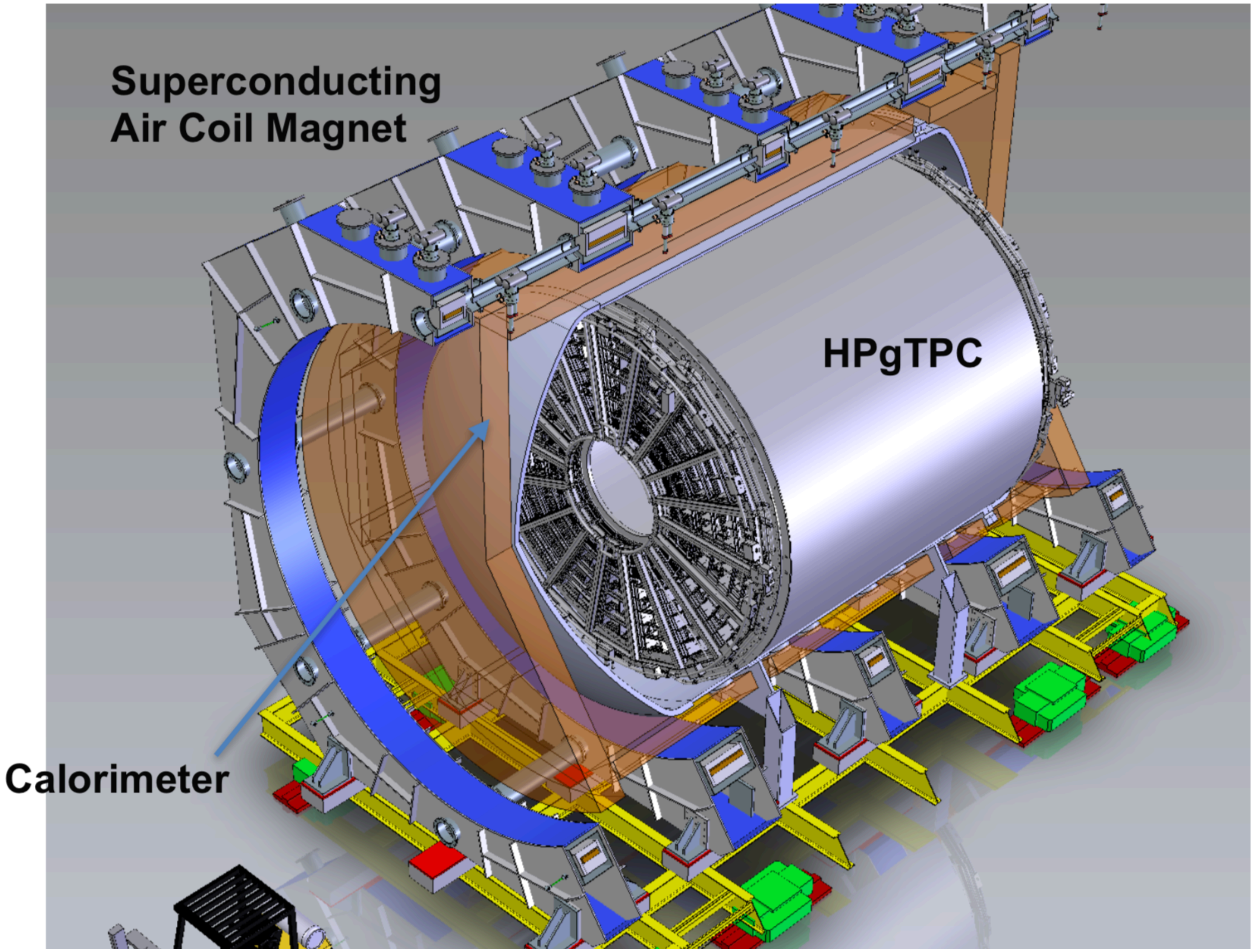
- Mechanical engineers at BARC working on PV will start into looking how to integrate ECAL into PV design - also needs some assumptions on ECAL structure / mechanics that are currently not more than educated guesses



The Boundary Conditions

A Large Detector

- The ECAL barrel surrounds the pressure vessel of the HPgTPC
  - Fiducial volume of TPC: 2.7 m radius, 5.5 m length
  - Inner dimensions of ECAL need to accommodate the PV - present assumptions (with endcaps inside PV):
    - ca. 2.8 m radius
    - ca. 6 m length



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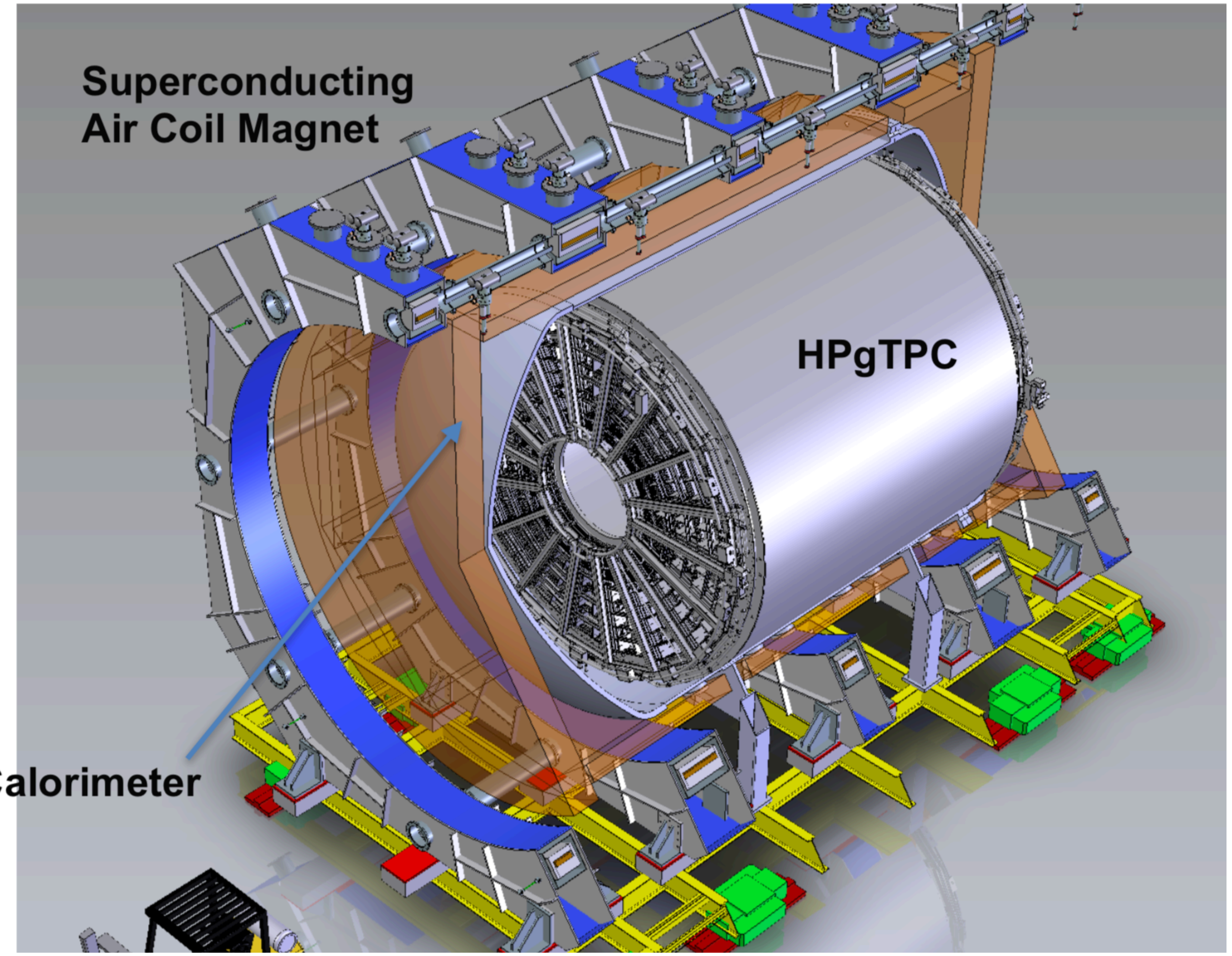
    that is a cylinder with a surface of $105.5\ m^2$, endcaps $2 \times 24.4\ m^2$



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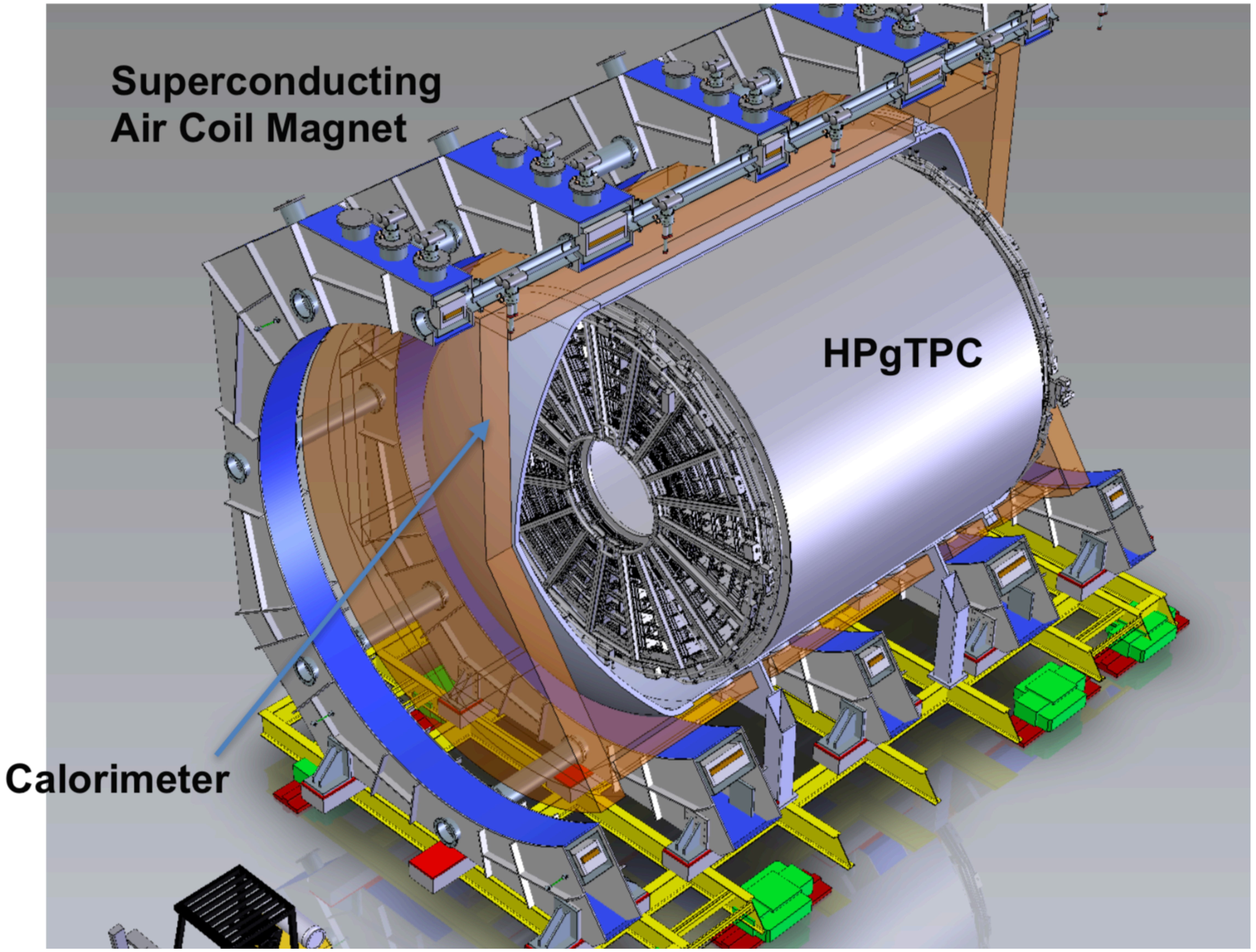
As comparison:

The CMS ECAL

inner radius 1.3 m, inner length ~ 5.8 m



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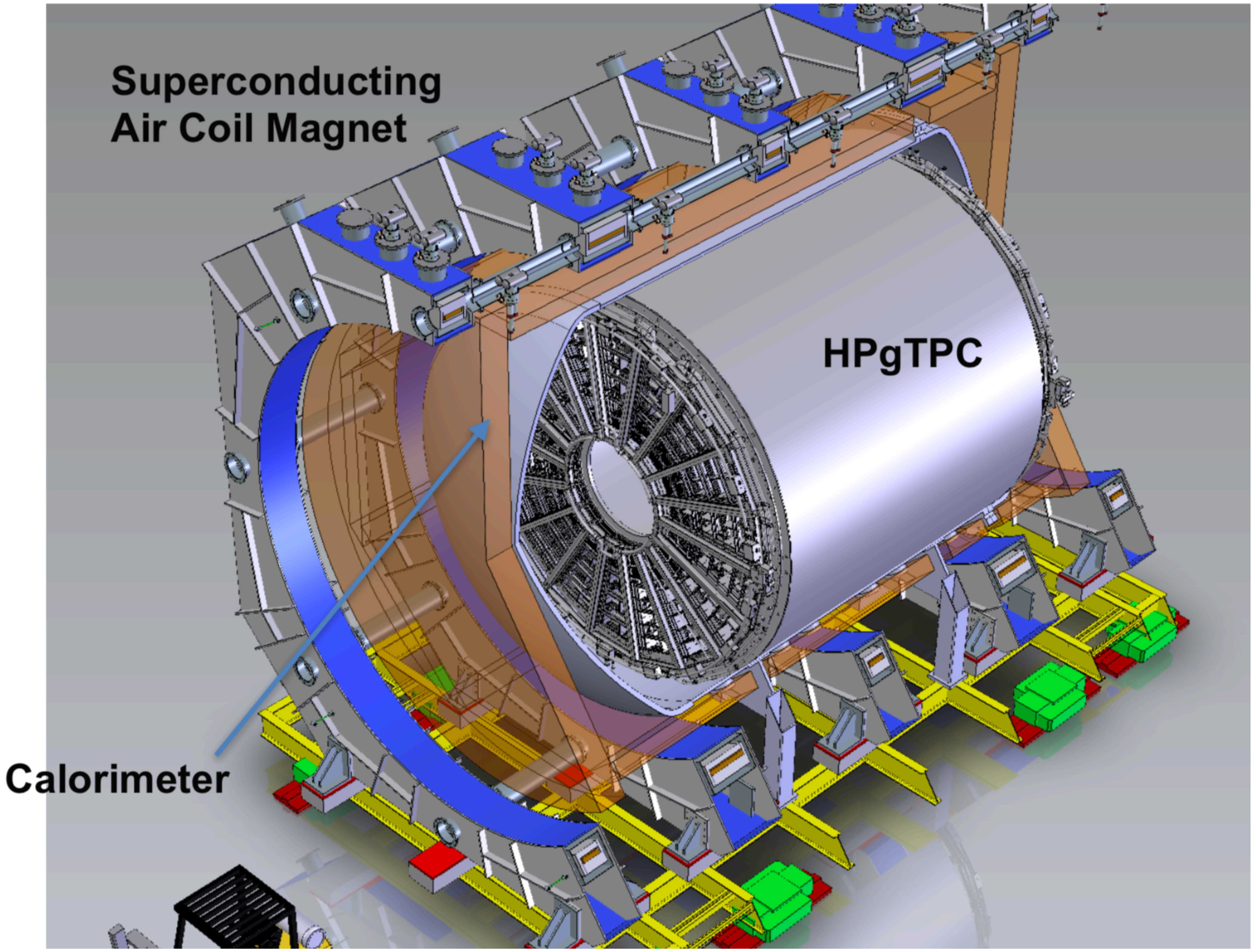


Scintillator tiles / strips with SiPM readout as active elements,

with long strips covering the bulk of the volume - depending on design:

~ 400k - ~ 3M electronics channels

A First Strawman ECAL Design - as in the CDR

Still subject to optimisation

- Need a calorimeter geometry that is fits the intrinsically planar geometry of the highly granular sampling structures, and matches the cylindrical HPTPC structure & pressure vessel:

First approach: An *octagonal* structure
NB: Also considering higher polygons (dodecagon, …) since this allows to have a deeper calorimeter while satisfying overall space constraints

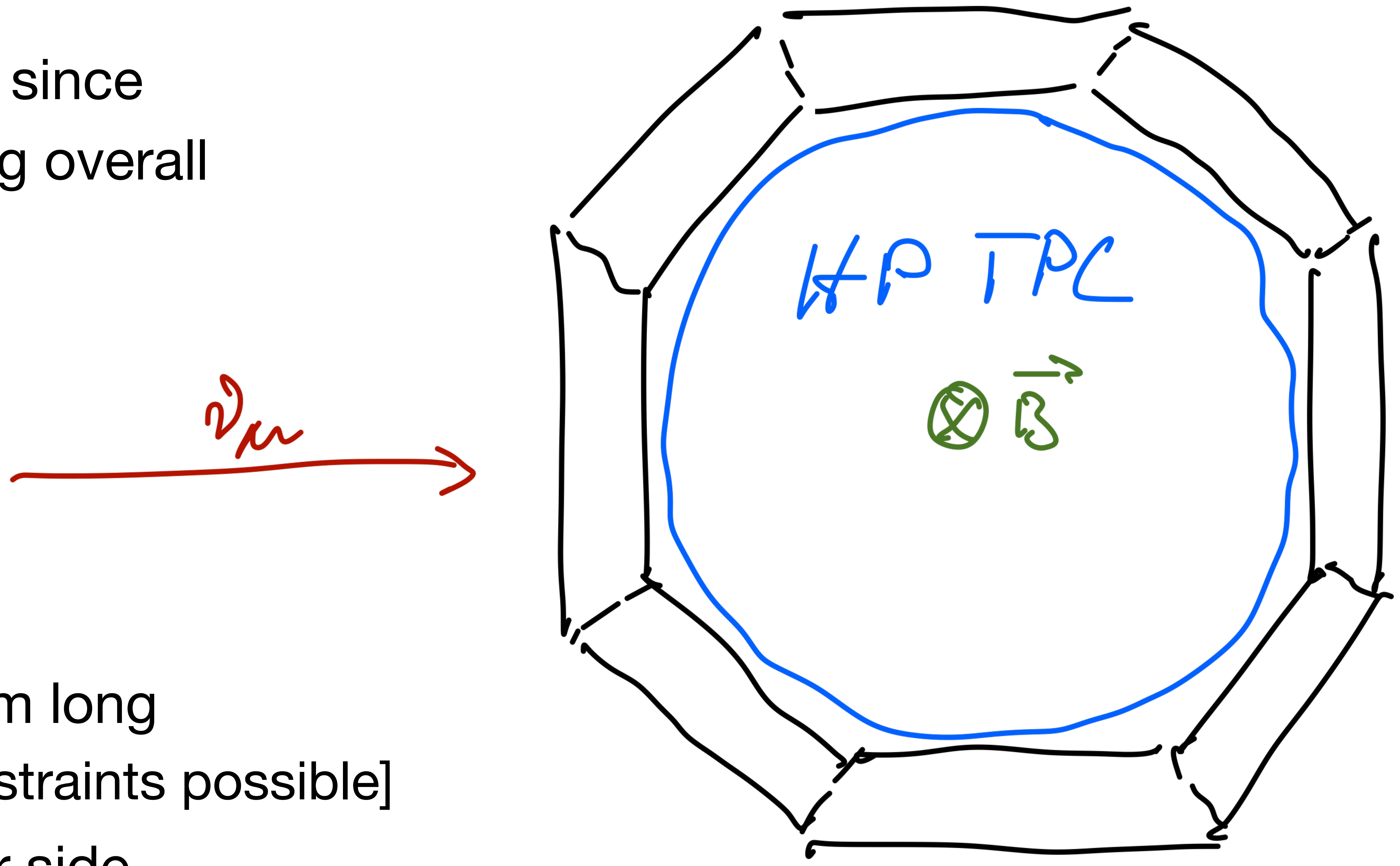
Magnetic field:

- parallel to drift direction (= cylinder axis)
- perpendicular to beam direction

For octagonal (CDR) layout:

Dimensions:

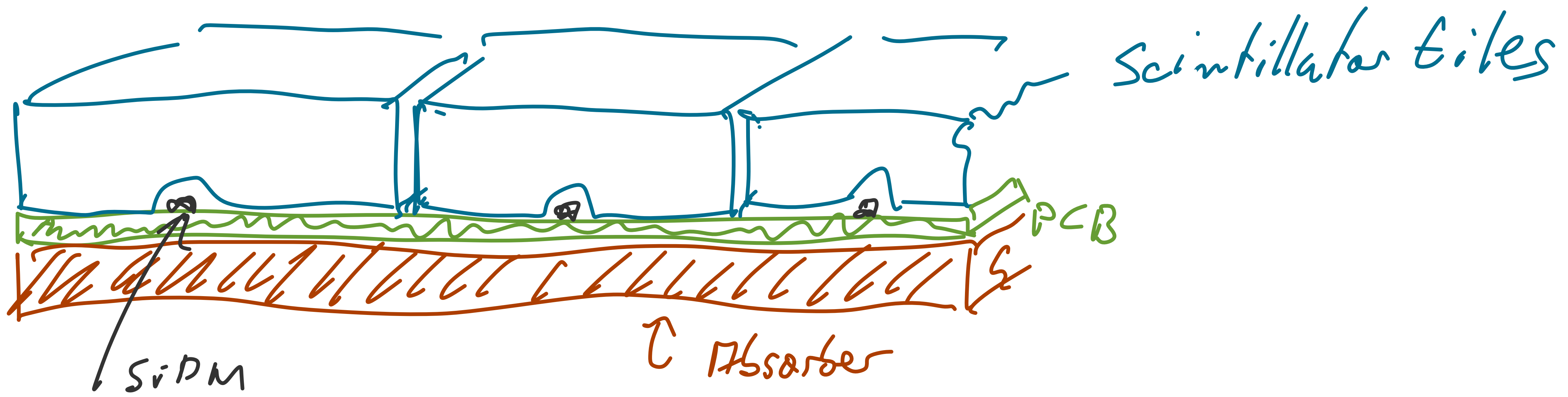
- Octagon side length: ~2.3 m (inner), ~2.6 m (outer)
- Barrel subdivided into 4 rings, each module ~ 1.46 m long
  [ad-hoc division - adjustments based on technical constraints possible]
- Endcaps subdividided into quarters - 4 modules per side



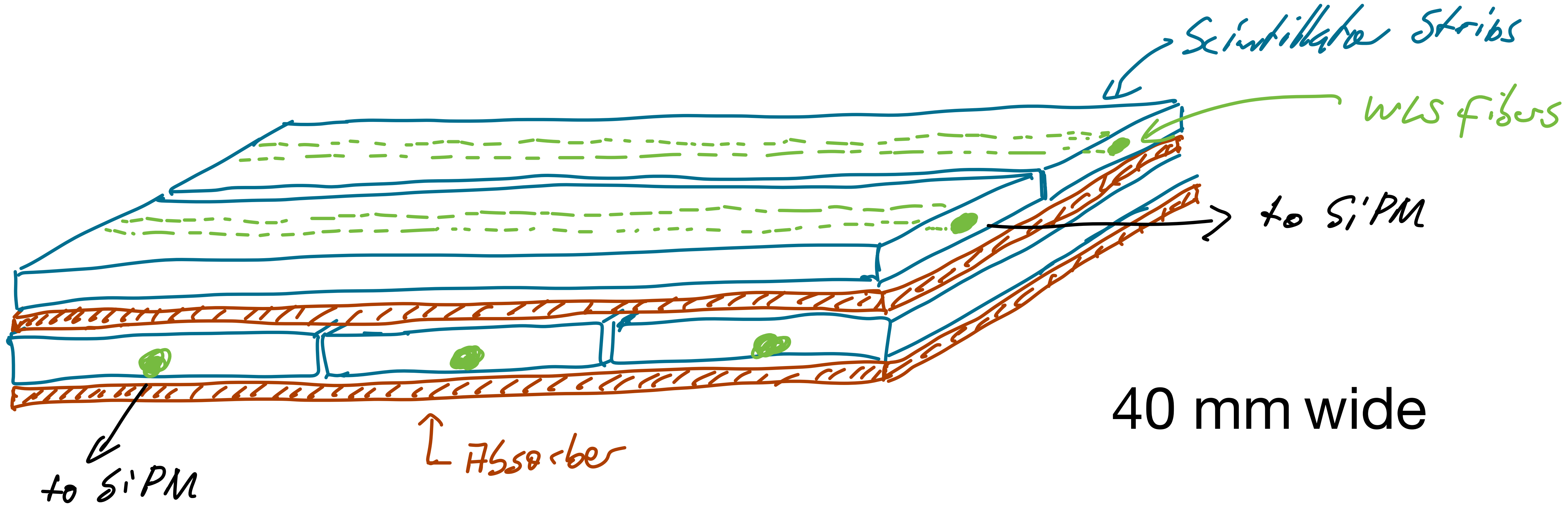
A First Strawman ECAL Design - as in the CDR

Active Elements & Absorbers

- Thin absorbers to achieve high sampling fraction & small stochastic term: **2 mm Cu**
  - Cu chosen as for small ρ_M/X_0, moderate X_0 : more “pointy” showers than with Pb
  - However: At the same X_0, Pb provides better energy resolution: An interesting option could be “sandwich” structures with Steel-cladded (or CF - cladded) Pb that also address the mechanical issues
- Two levels of granularity in readout: Tiles and strips, both plastic scintillator with SiPM r/o, 5 mm thick



25 x 25 mm²

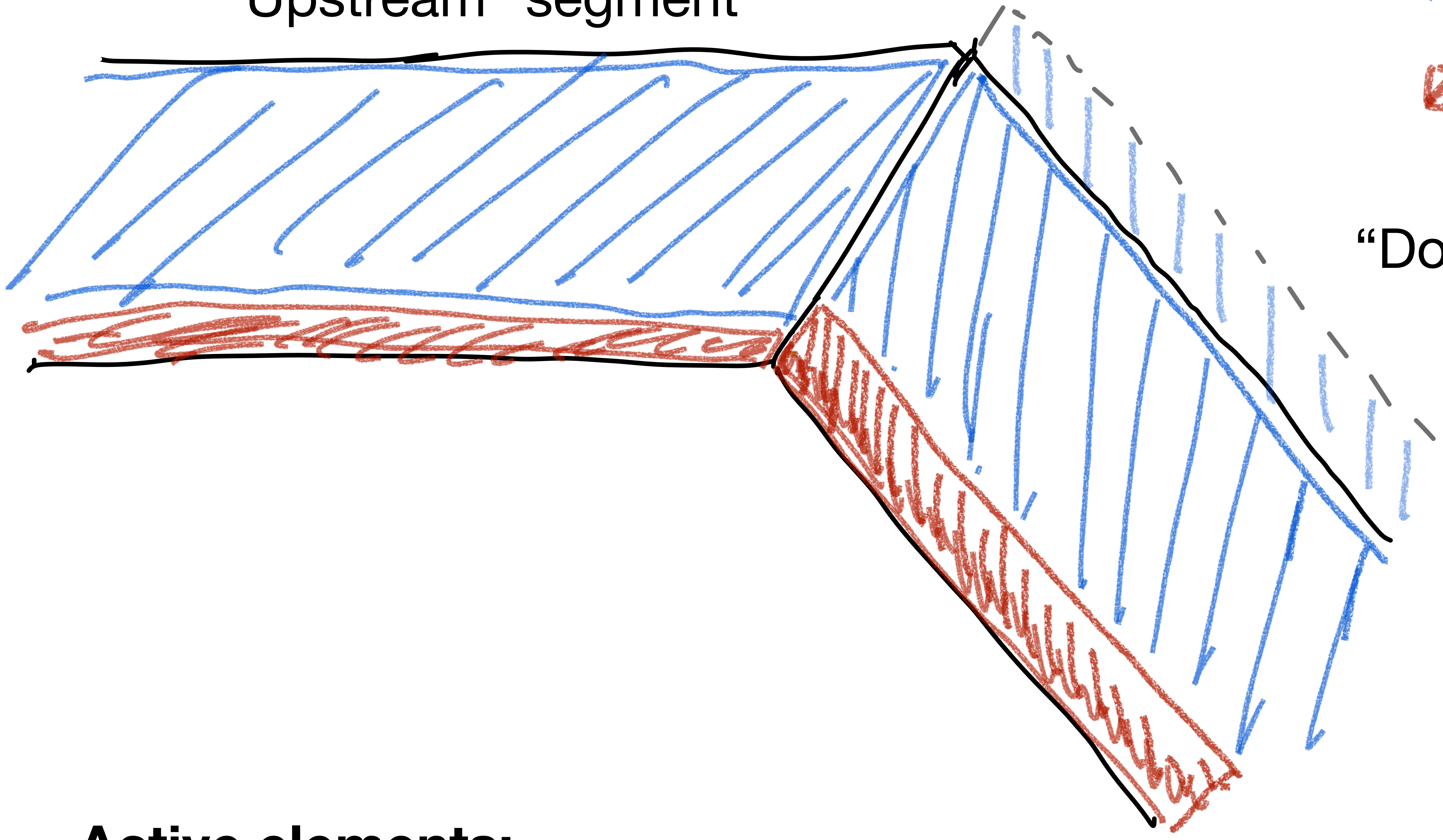


40 mm wide

- High granularity only in first 8 (6) layers for 3 downstream (5 upstream) segments - to be optimized
- Assuming spatial resolution along strip via time difference in two-sided readout + using “strip splitting” across adjacent layers

A First Strawman ECAL Design

Upstream / Downstream Variations



low granularity layers: alternating orthogonal bars

high granularity layers: tiles

- Downstream layout [3 downstream octagon segments]:
  - 60 layers, first 8 high granularity [benefits for energy resolution with 20 additional layers, geometrically possible in dodecadon - layout]
- Upstream layout [5 side and upstream segments, endcaps]:
  - 60 layers, first 6 high granularity

Active elements:

- *high granularity*: 25 x 25 mm^2 tiles, 5 mm thick
- *low granularity*: 40 mm wide, 5 mm thick bars over full module length, crossed in alternating layers

A Word on Time

Based on current best estimates

- Now: Near Detector CDR
- End 2021: Near Detector TDR
  - MoUs for ND ~ 2022
- 2028/2029: First Beam

➫ Production from 2024

Extras

ECAL Cost

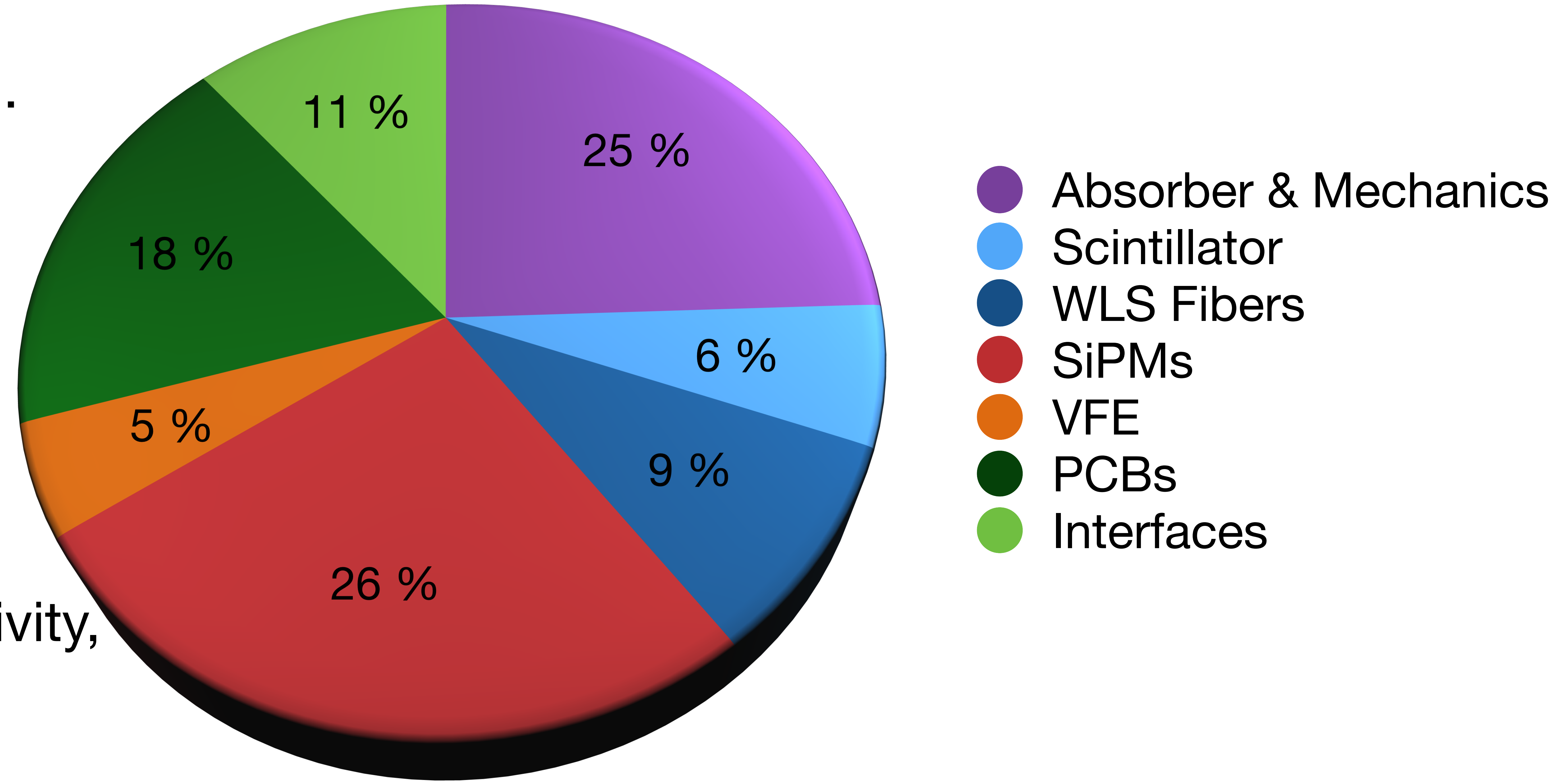
- CORE Cost (incomplete - missing production / installation tooling, yield, off-detector systems & services,…)
  - Note: Still assuming 7.3 m long barrel - will probably be < 6 m, probably reduces cost by 10 - 15%
- Mainly a spreadsheet exercise, based on:
  - Cost information from Belle II, CMS HGCAL, CALICE AHCAL & TCMT
  - Educated guesses & rough estimates

Not even preliminary - to be taken with a large grain of salt, primarily as a discussion starter

Cost: The Default Design

Showing Division across Key Items

- Based on the current design presented by Eldwan (8 HG, 52 LG layers DS, 6 HG, 54 LG layers US)
  - Results in ~2.7 M channels, ~ 90% in the HG elements
  - Cost estimates based on
    CALICE AHCAL, CMS HGCAL, Belle II KLM,…
- Size matters:
  - ~ 29 m^3 absorber (when using Cu)
  - ~ 73 m^3 scintillator
  - ~ 325 km fibers
  - ~ 1500 m^2 PCB for HG layers
    NB: Strips also need PCBs for SiPM connectivity, ASICS - here assume 150 m^2

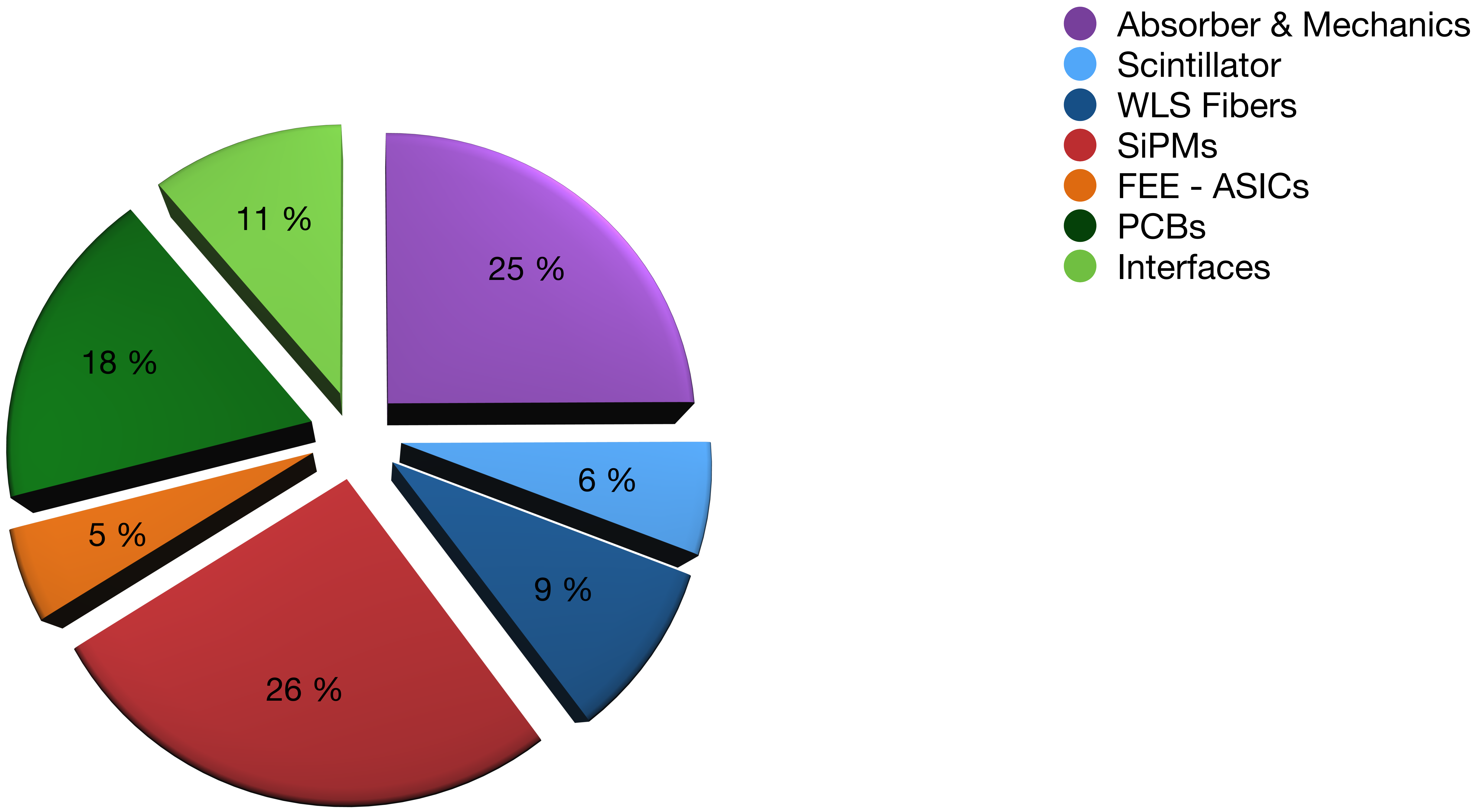


- Channel count the main cost driver - clearly need to understand how much is needed / can be justified (*also remarked by LBNC*)

➩ Have to find an optimal working point in terms of performance, feasibility and "technological interest"

Cost: The Default Design

Zooming in on scaling expectations



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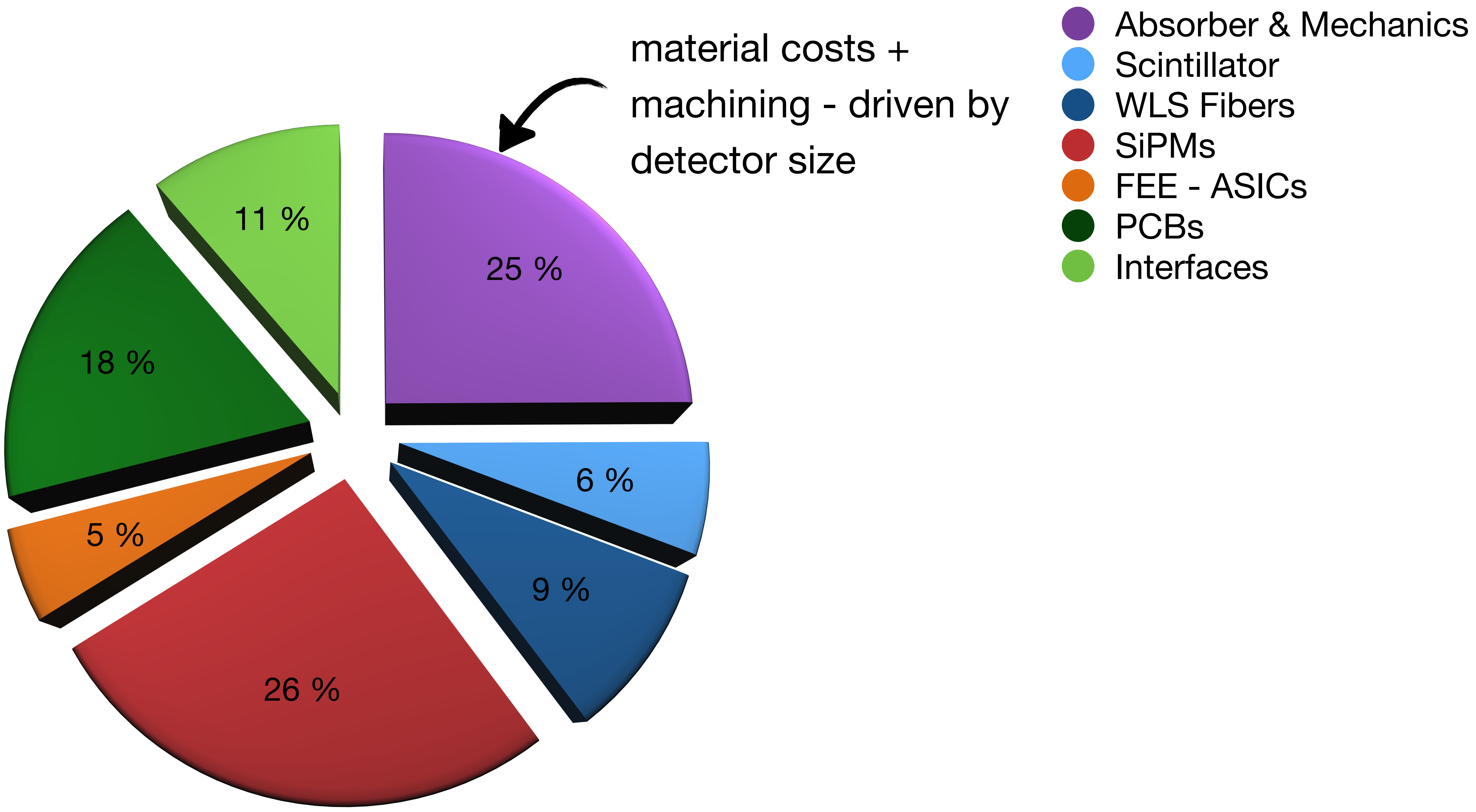

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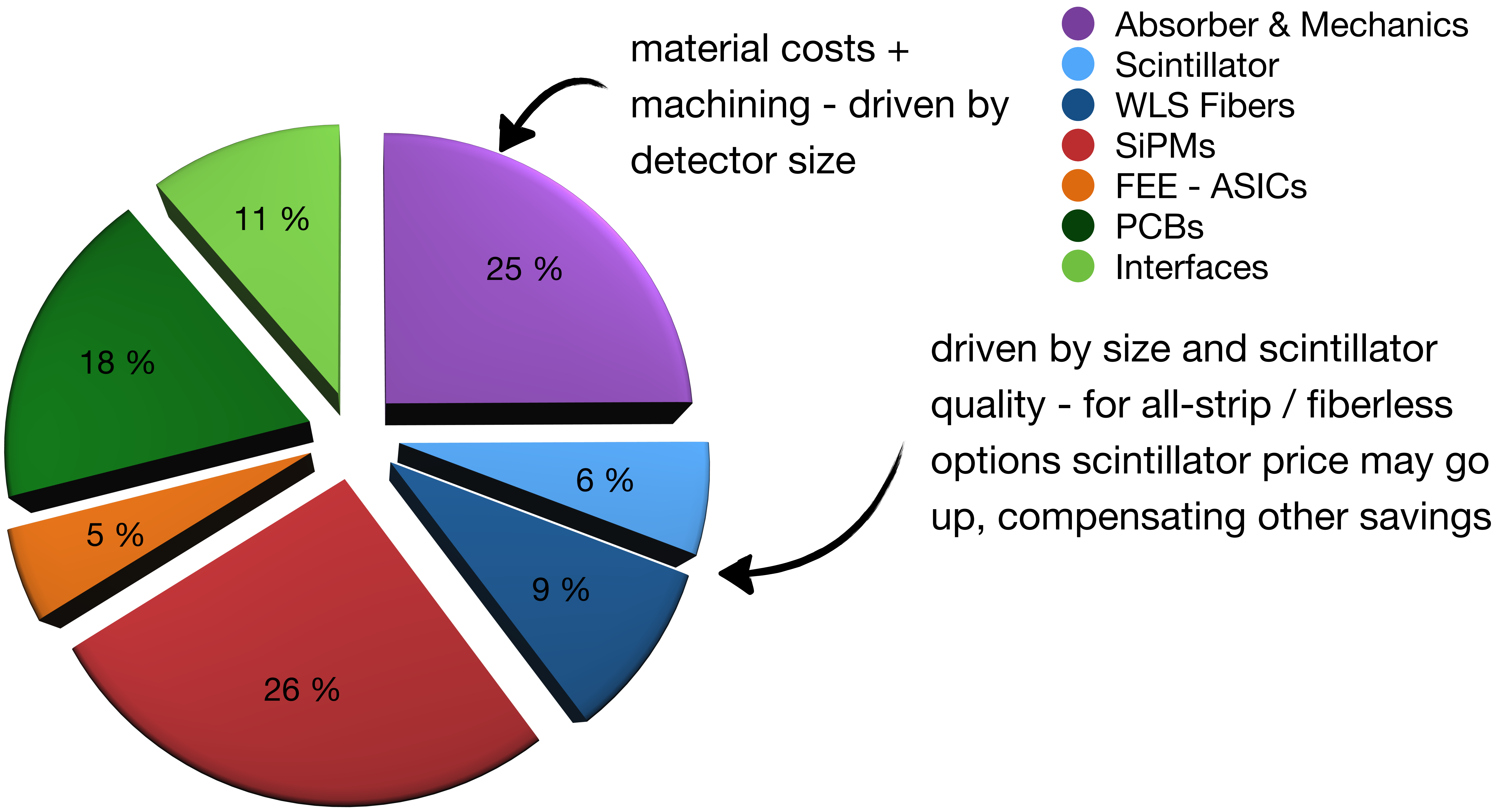

material costs + machining - driven by detector size

driven by size and scintillator quality - for all-strip / fiberless options scintillator price may go up, compensating other savings

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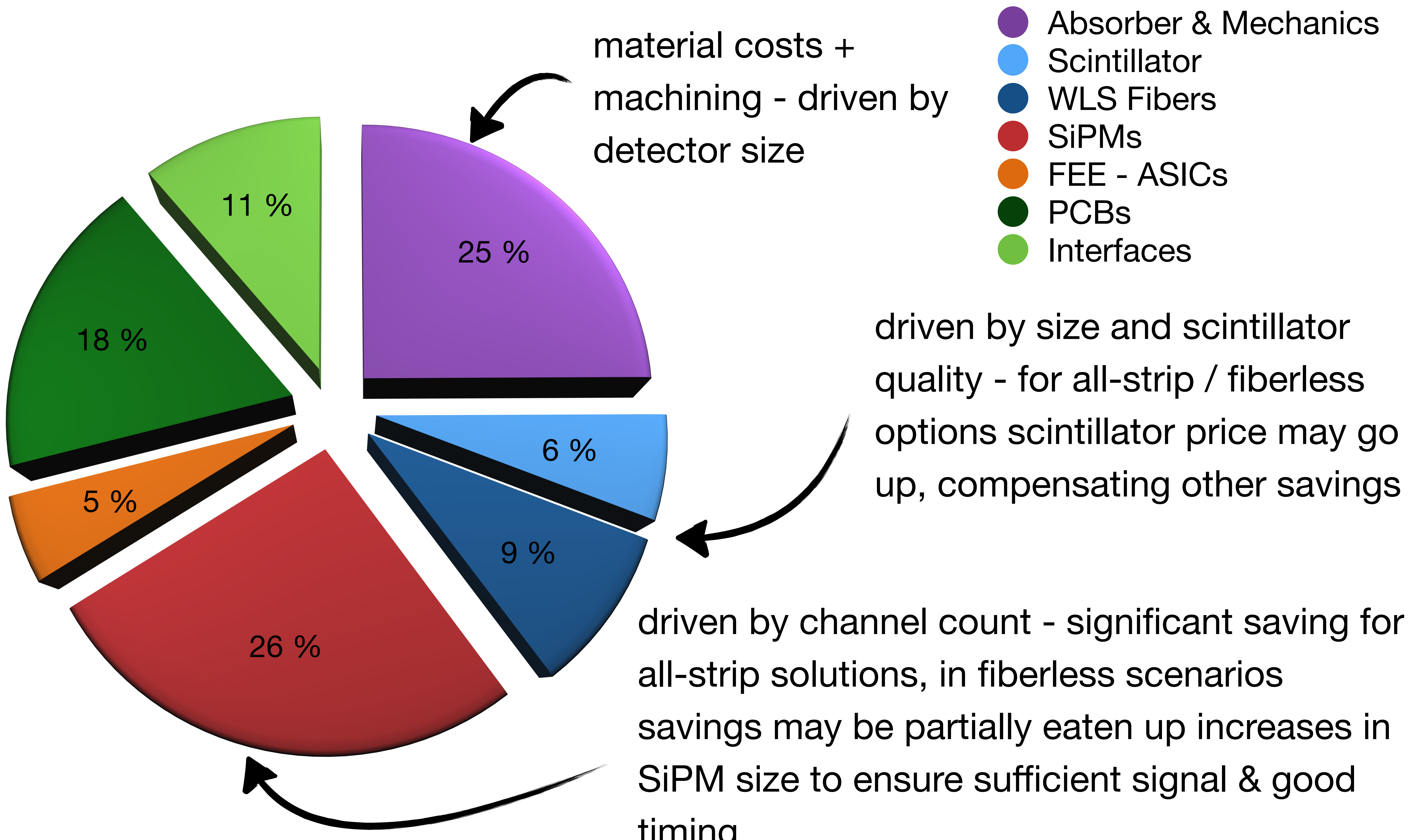


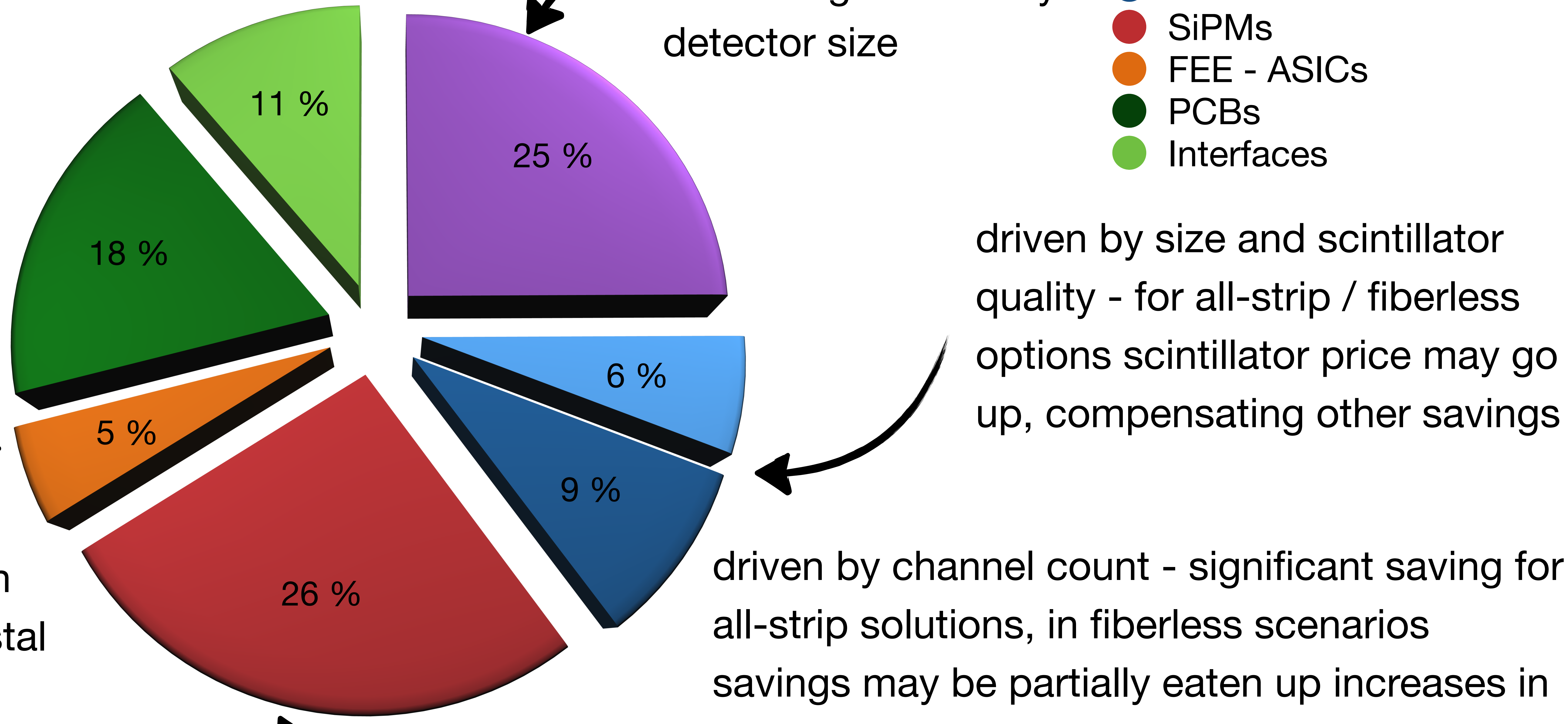
material costs + machining - driven by detector size

driven by size and scintillator quality - for all-strip / fiberless options scintillator price may go up, compensating other savings

driven by channel count - significant saving for all-strip solutions, in fiberless scenarios savings may be partially eaten up increases in SiPM size to ensure sufficient signal & good timing

Cost: The Default Design

Zooming in on scaling expectations



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ASIC + associated costs driven by channel count + cost pedestal

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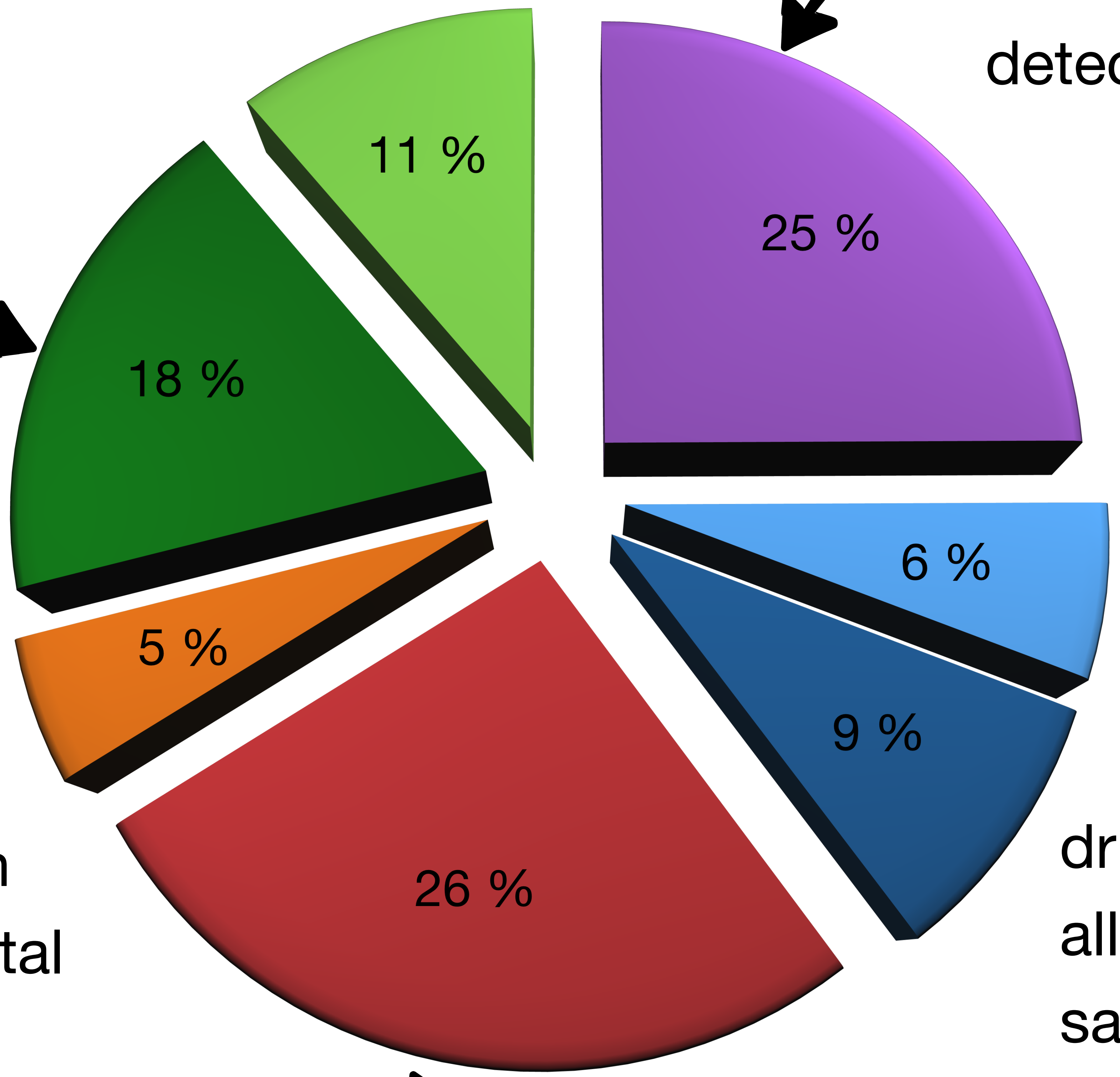

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ASIC + associated costs driven by channel count + cost pedestal

PCB for HG elements - driven by area (= number of layers) of HG elements

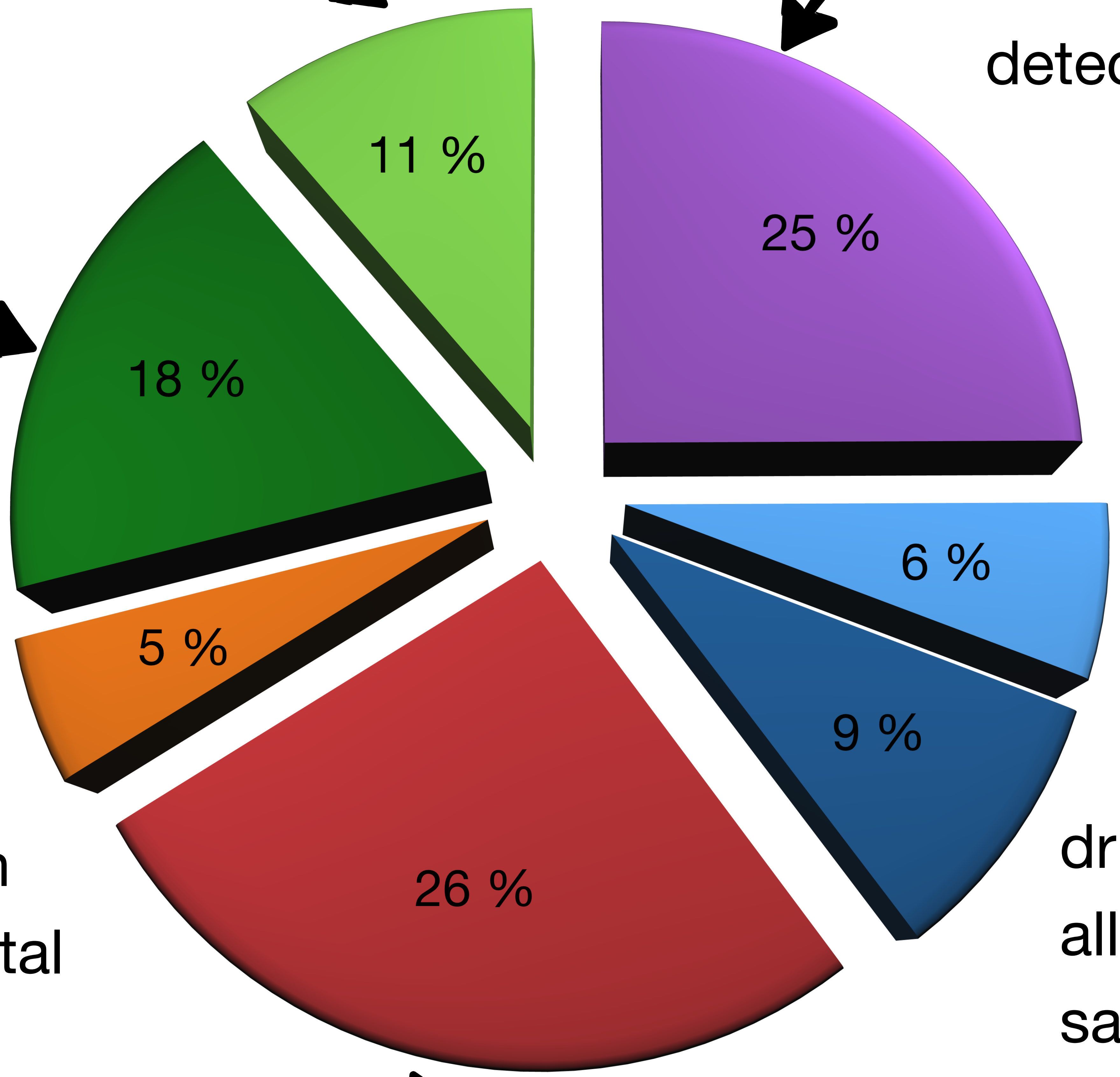
Cost: The Default Design

Zooming in on scaling expectations

Interfaces (data collection, calibration, control) - assuming 10 LG layers can share one system, HG layers need one per layer

PCB for HG elements - driven by area (= number of layers) of HG elements

ASIC + associated costs driven by channel count + cost pedestal



material costs + machining - driven by detector size

- Absorber & Mechanics
- Scintillator
- WLS Fibers
- SiPMs
- FEE - ASICs
- PCBs
- Interfaces

driven by size and scintillator quality - for all-strip / fiberless options scintillator price may go up, compensating other savings

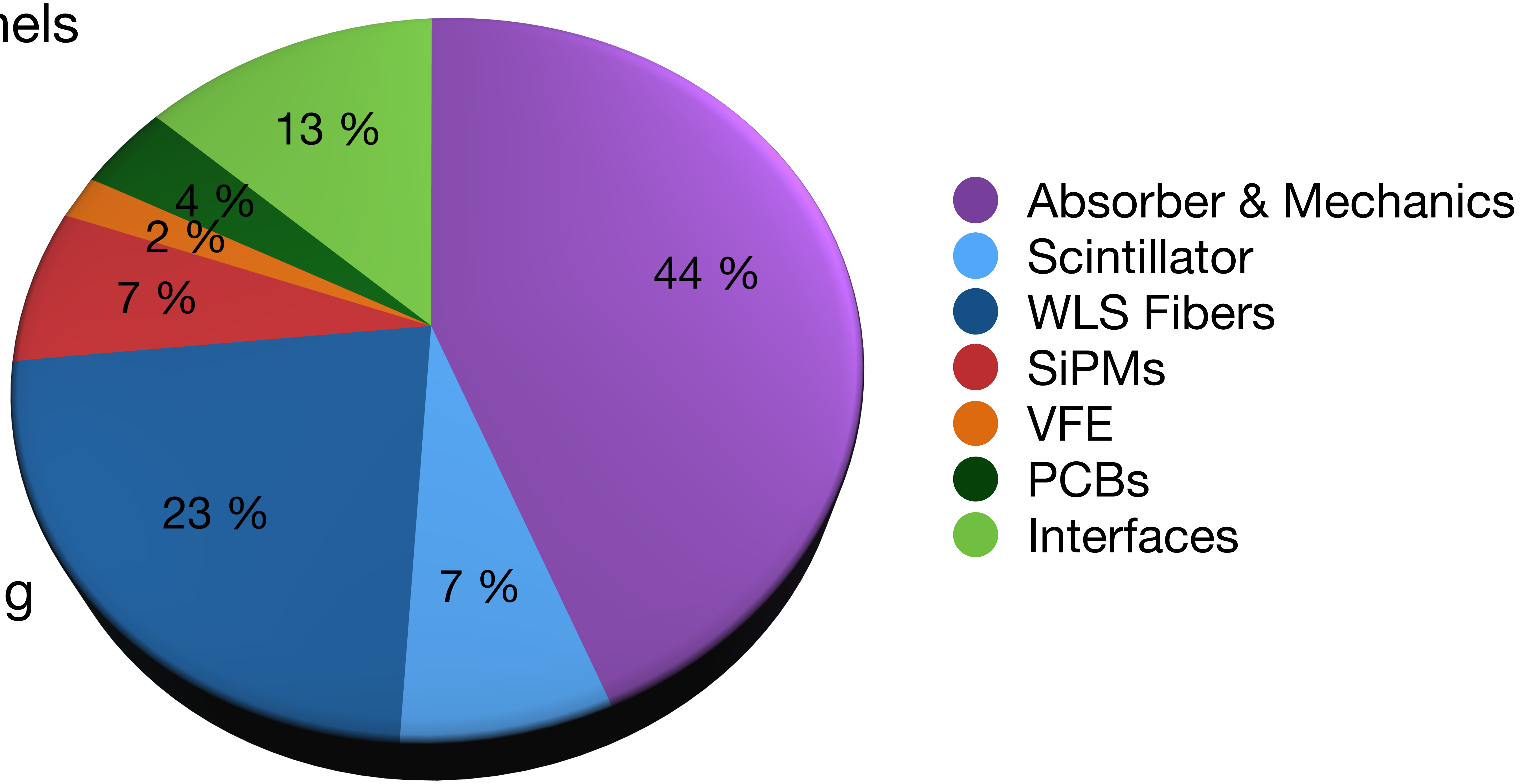
driven by channel count - significant saving for all-strip solutions, in fiberless scenarios savings may be partially eaten up increases in SiPM size to ensure sufficient signal & good timing

Cost: Strips Only

Showing Division across Key Items

- Using crossed strips everywhere
  - To recover some granularity, using 30 mm wide strips throughout
  - Results in a total of 213k strips => 426k channels
  - Same “metrics” for cost estimate

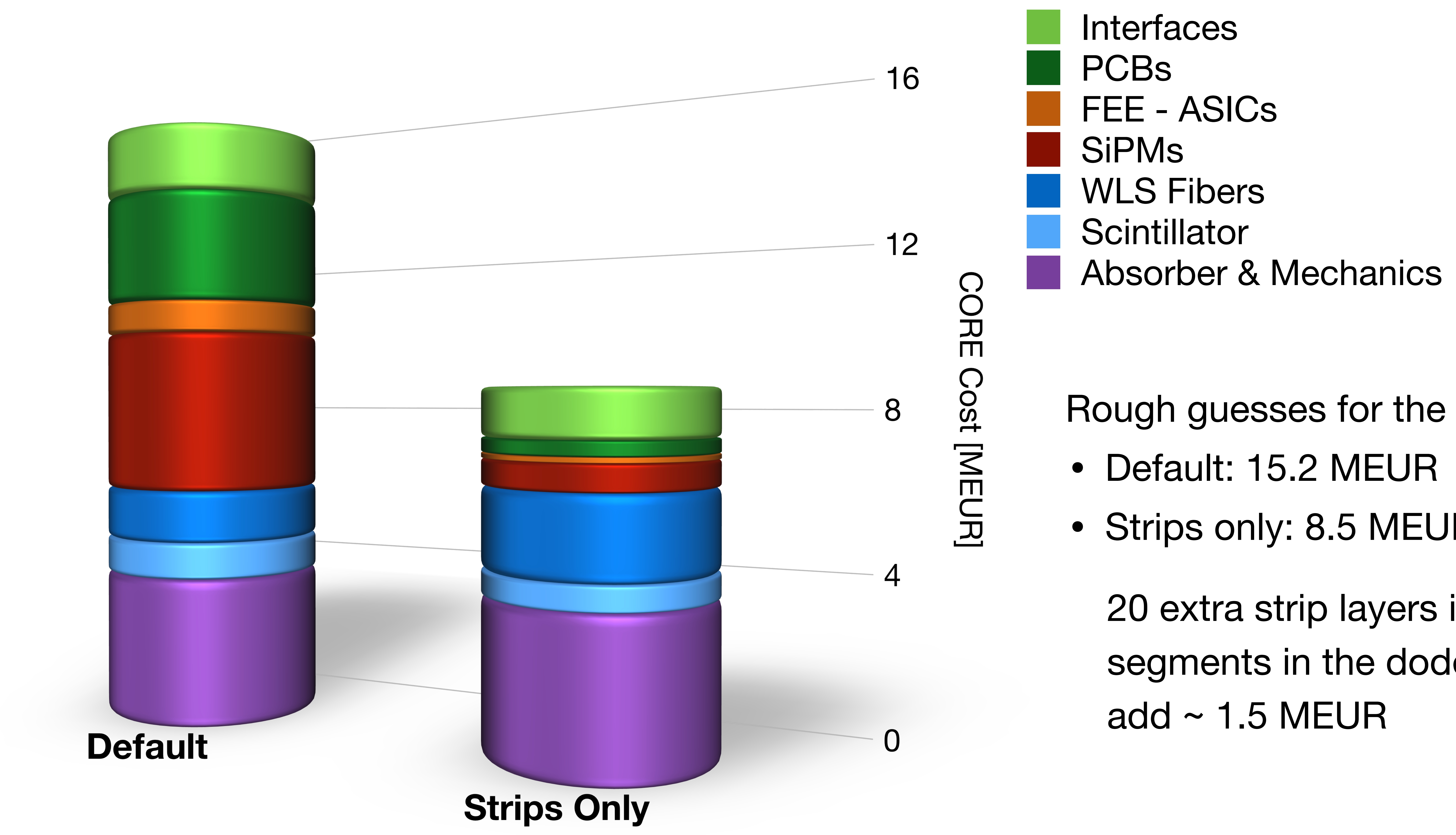
- Lengths, Areas & Volumes:
  - ~ 29 m^3 absorber (when using Cu)
  - ~ 73 m^3 scintillator
  - ~ 480 km fibers
  - ~ 210 m^2 PCB for SiPM / strip & ASIC coupling



- Substantially lower channel count than systems with high granularity layers - fiberless strip readout may provide better timing, eliminates need for fibers, but will require larger (= more costly) SiPMs, and higher quality (= more costly) scintillator

Comparing Two Extremes: Default and Strip only

Rough absolute Cost



Rough guesses for the total costs:

- Default: 15.2 MEUR
- Strips only: 8.5 MEUR

20 extra strip layers in the downstream barrel segments in the dodecadon geometry would add ~ 1.5 MEUR