The MPD ECAL - Introduction

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DEEP UNDERGROUND NEUTRINO EXPERIMENT

DUNE Near Detector Workshop
DESY, October 2019

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Outline

- High-level motivation
- ECAL Concept
  - Technology choices & options
- First Cost Estimate and main Cost Drivers
- R&D Items

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
  - …

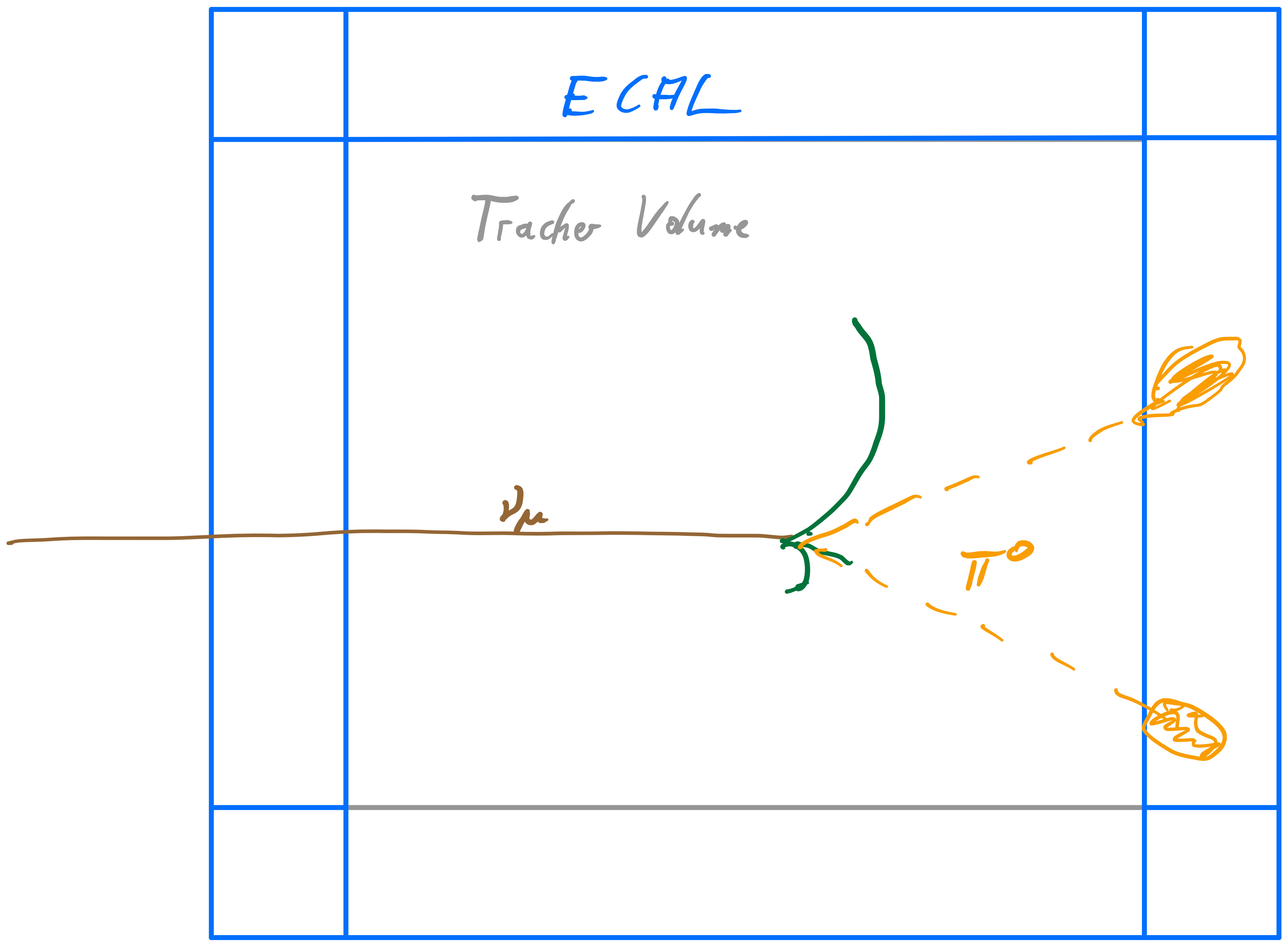
⇨ Energy range from ~ 50 MeV to ~ 2 GeV: Small stochastic term crucial

⇨ Requires longitudinal segmentation

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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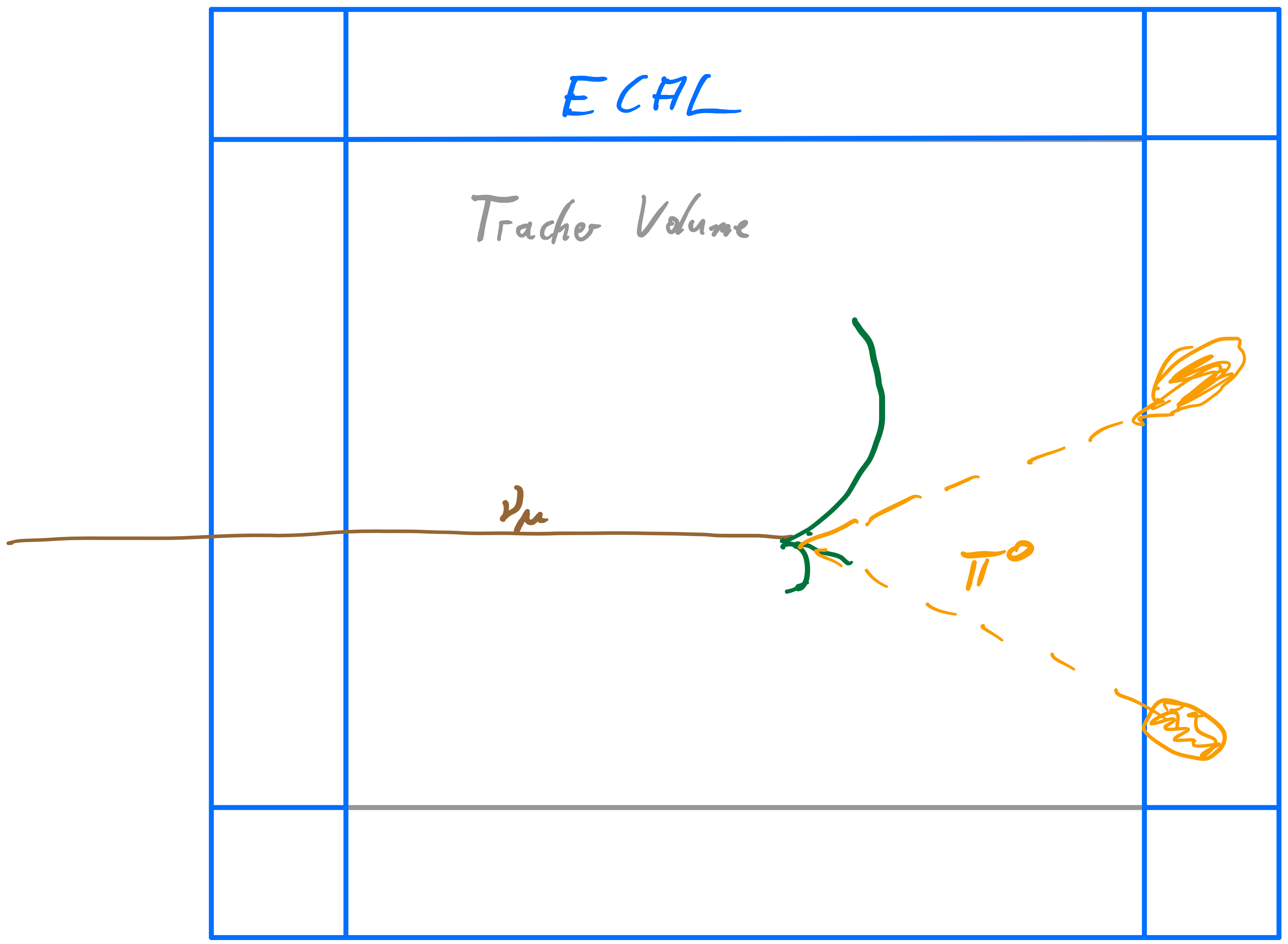
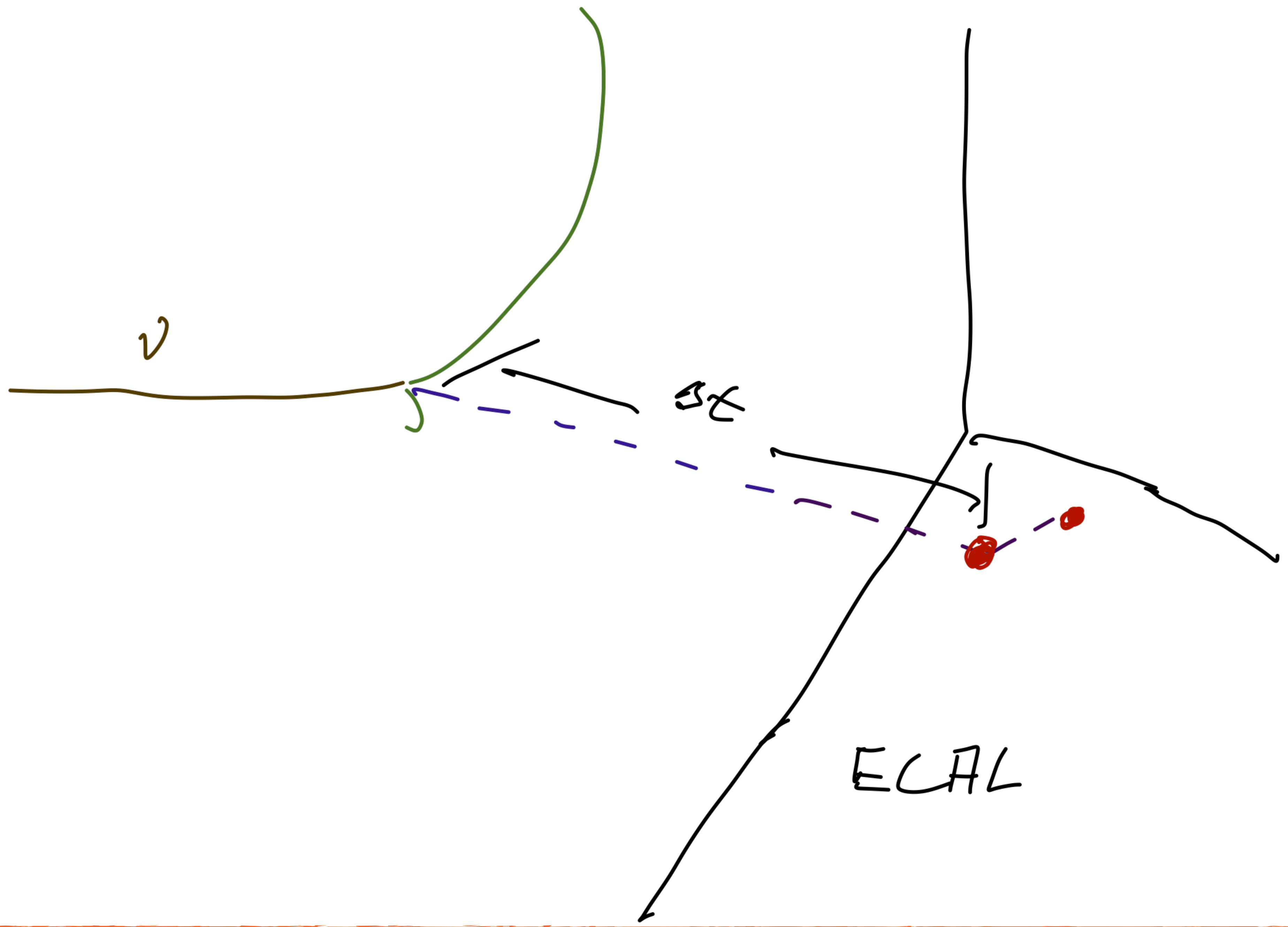


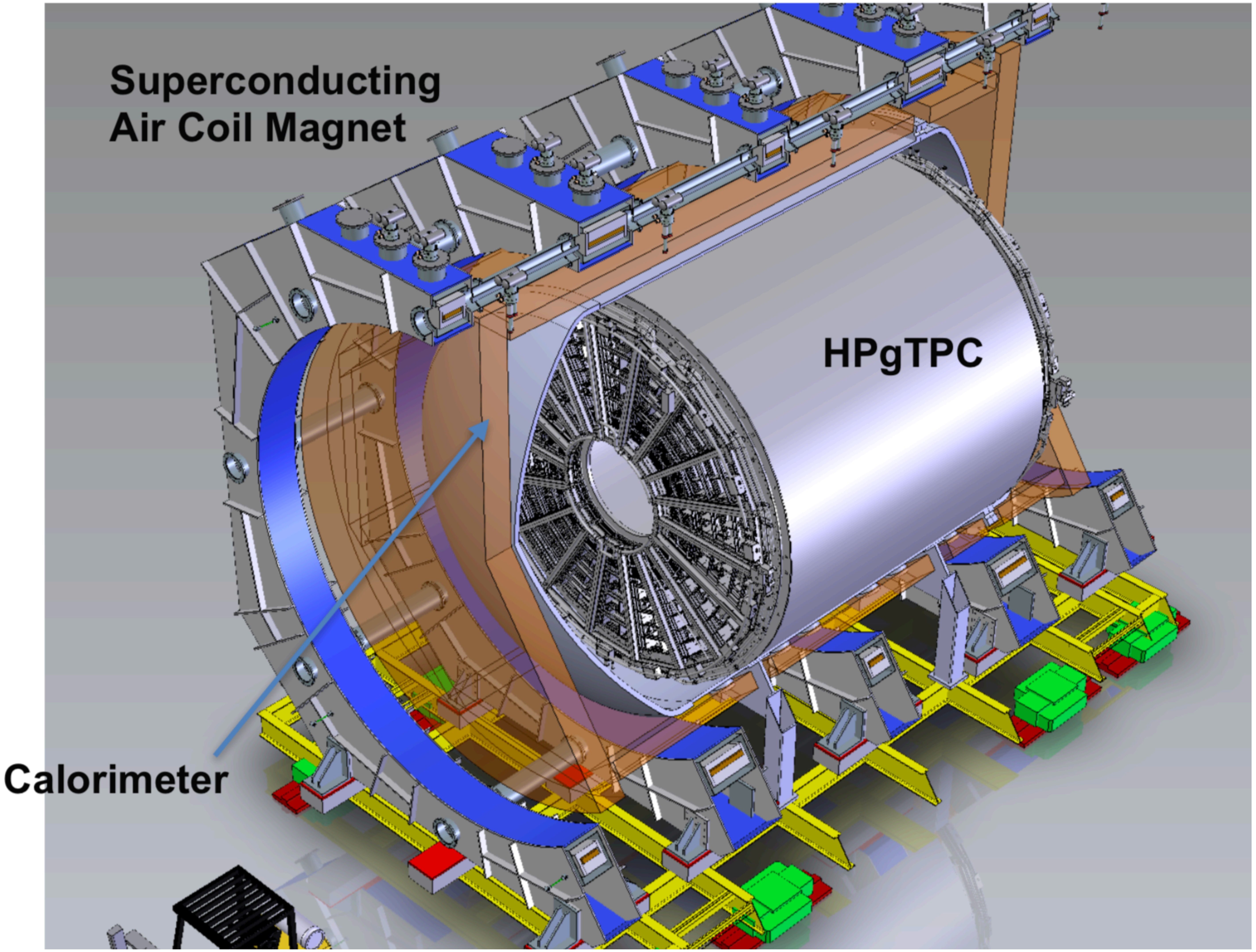
- Neutron reconstruction - a potential game-changer [still needs to be established in realistic environments!]
  - Requires timing on the few 100 ps level to enable energy measurement via time-of-flight



The Boundary Conditions

A Large Detector

- The ECAL 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:
    - 2784.5 mm radius
    - 7288.5 mm length



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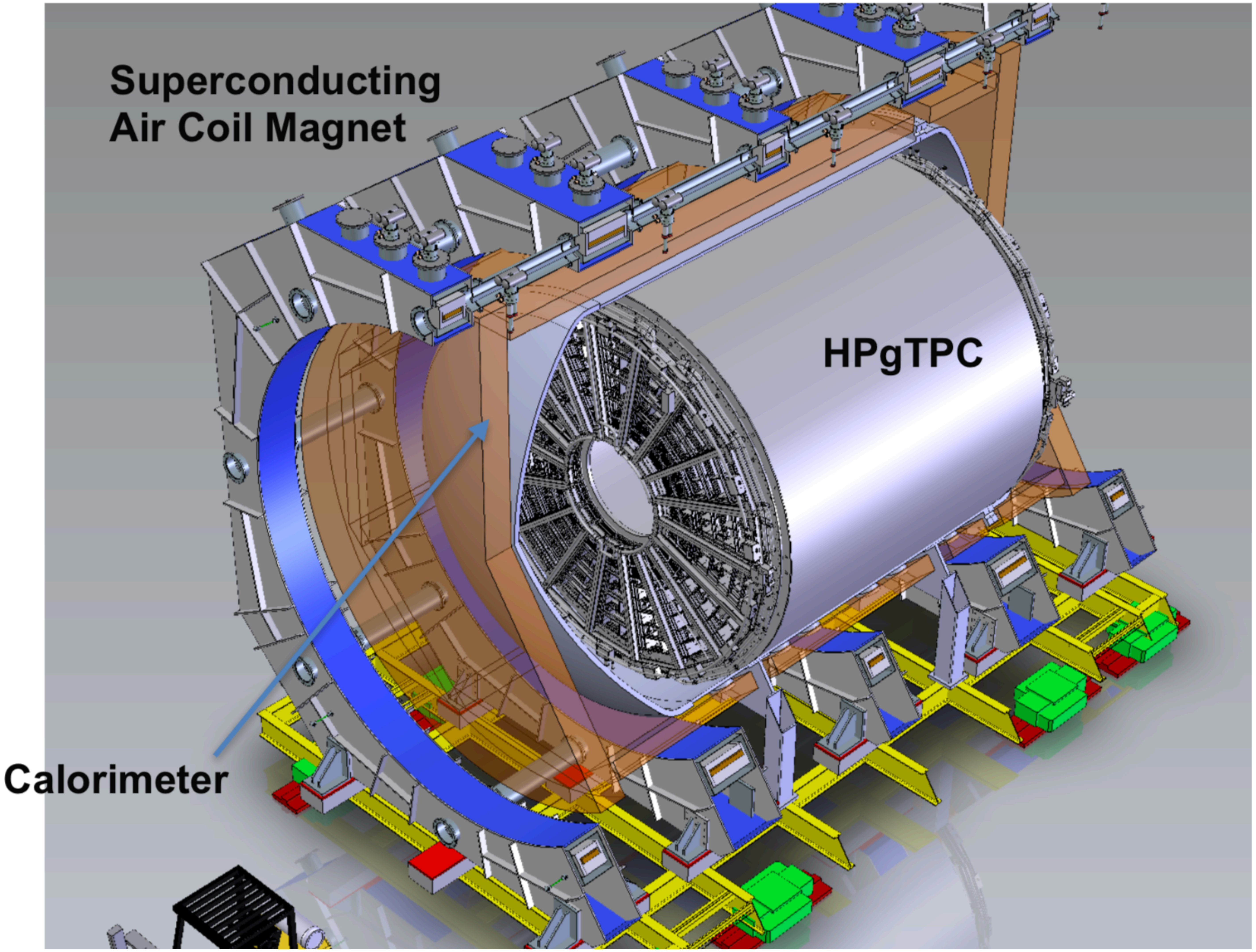

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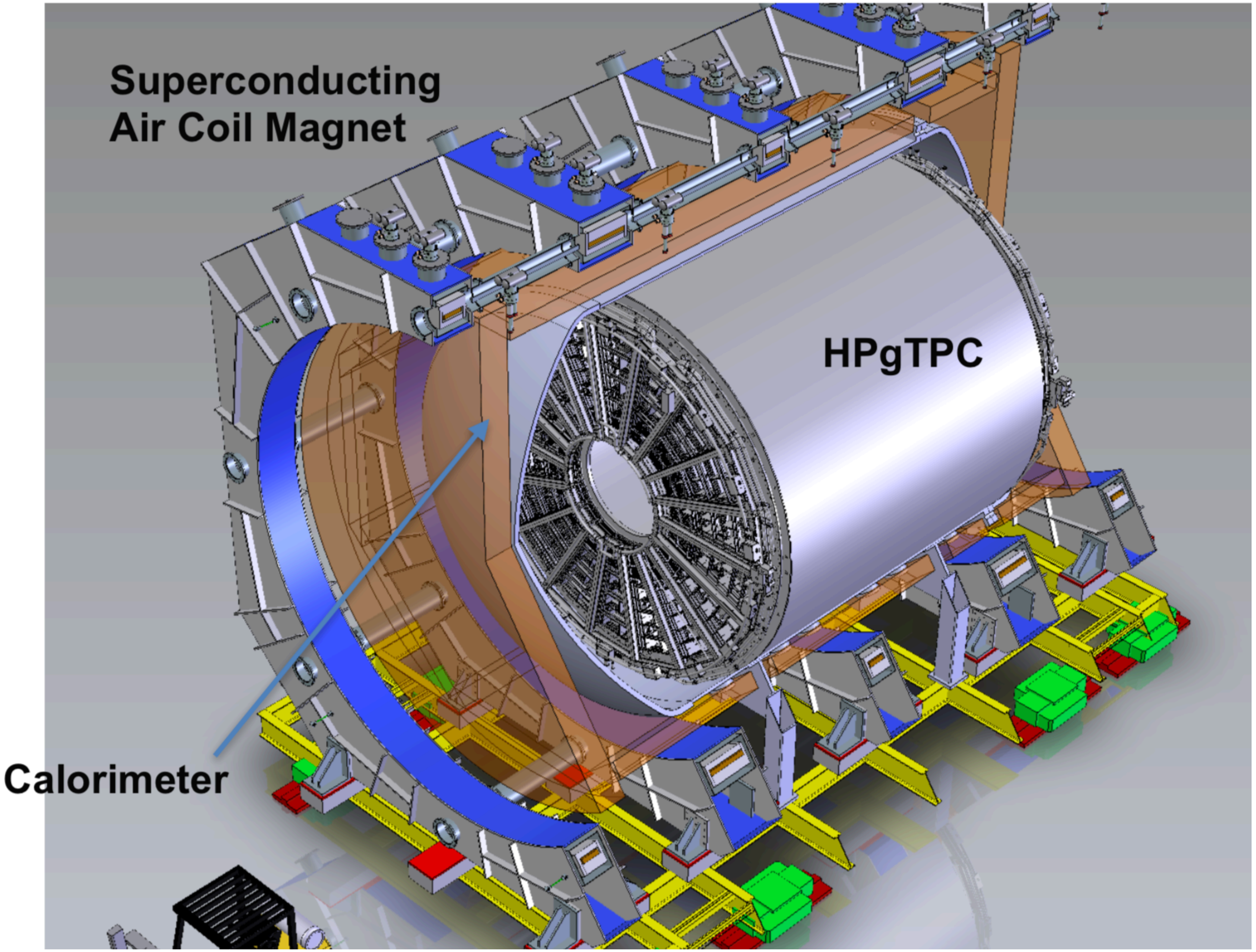
As comparison:

The CMS ECAL

inner radius 1.3 m, inner length ~ 5.8 m



The Global Layout

Still subject to optimisation

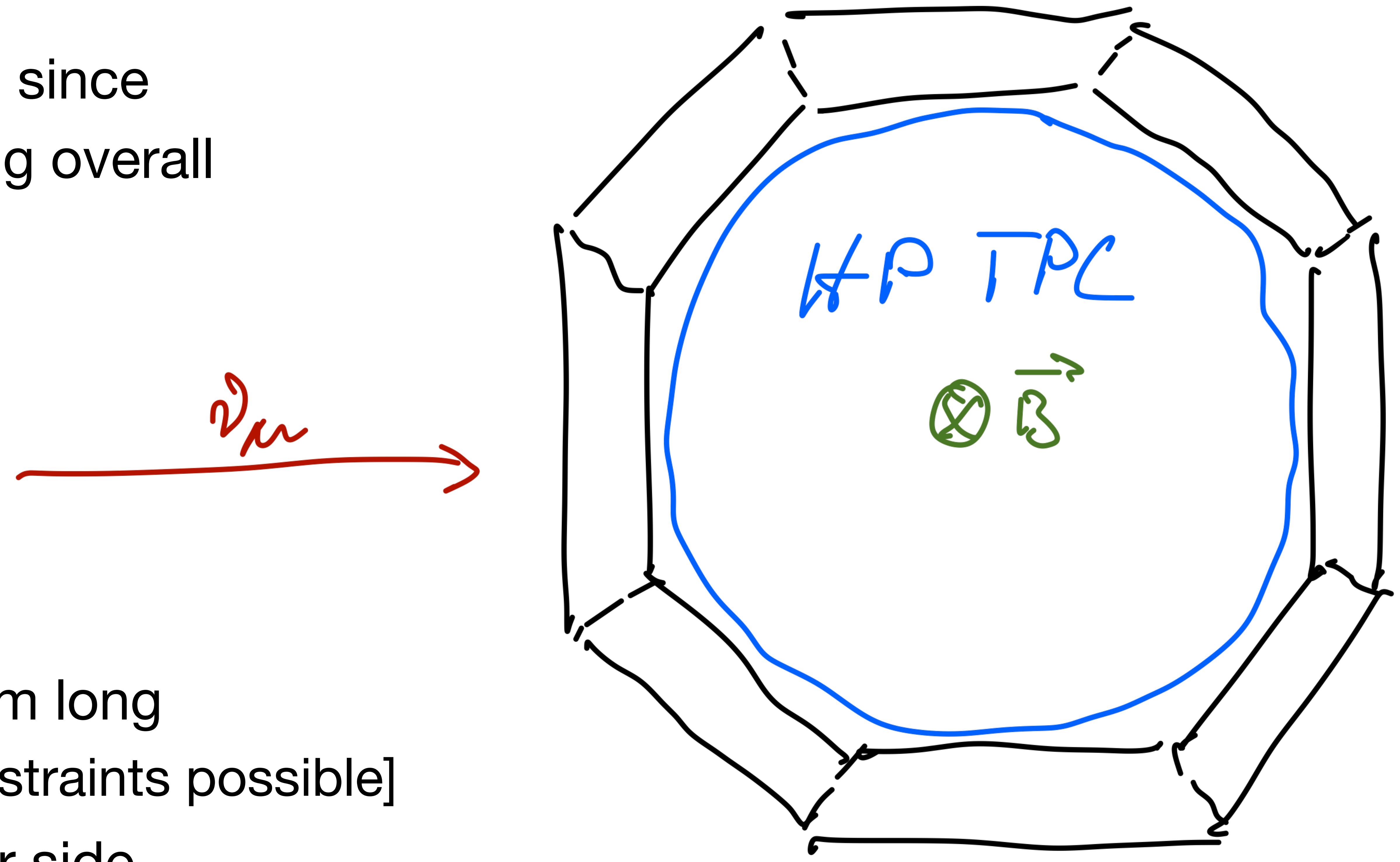
- Need a calorimeter geometry that is fits the intrinsically planar geometry of the highly granular sampling structures, and matches the cylindrical HPTPC structure & pressure vessel:

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

  For now, assuming octagonal layout

  Dimensions:
  - Octagon side length: ~2.3 m
  - Barrel subdivided into 5 rings, each module ~ 1.46 m long
    [ad-hoc division - adjustments based on technical constraints possible]
  - Endcaps subdividided into quarters - 4 modules per side

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



The Global Layout

Accounting for environment and constraints

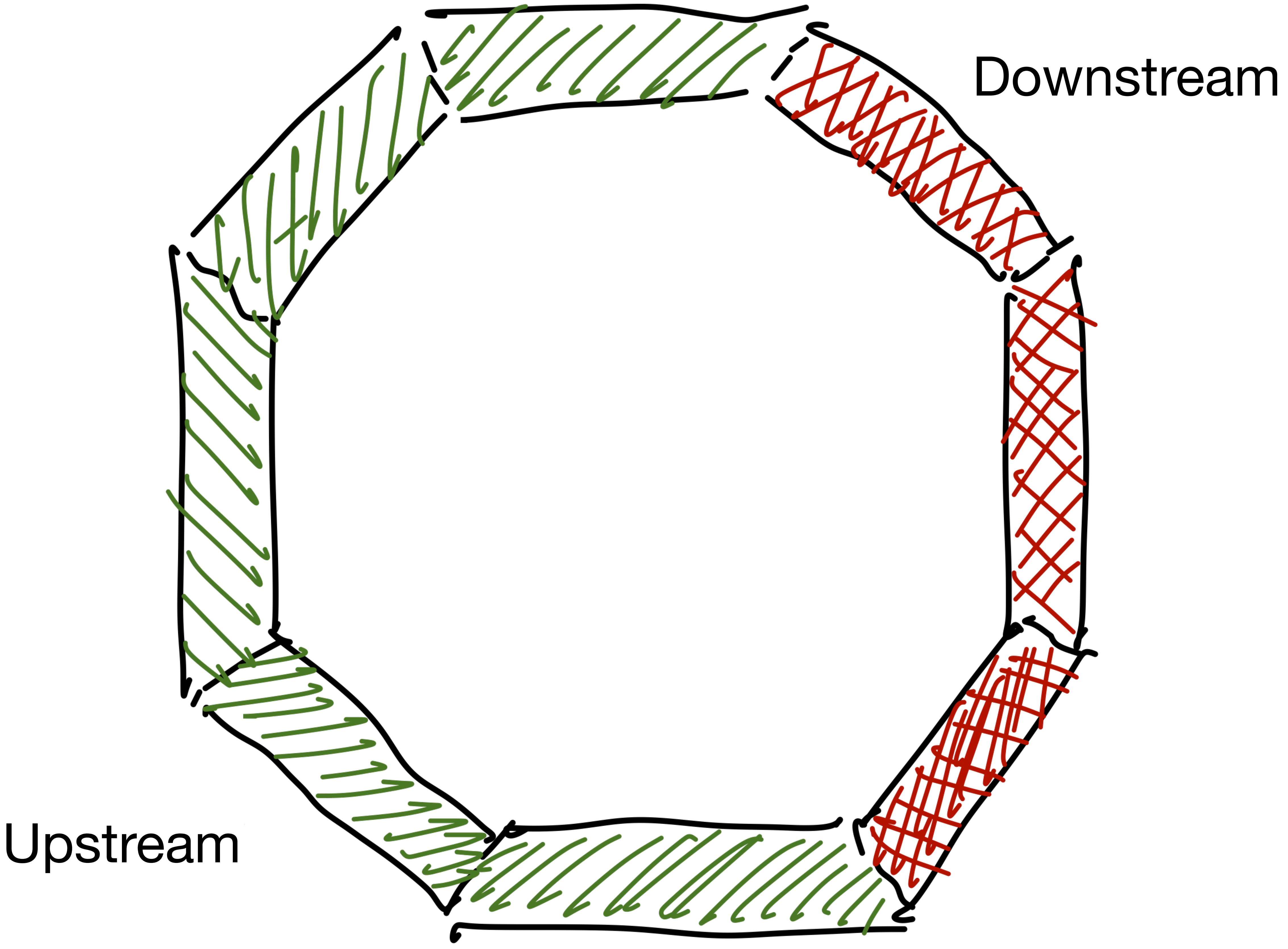
- Things tend to go forward - do not need the same granularity, and same depth / resolution everywhere
    - Obviously something that requires understanding and optimisation - in progress

Defining two regions:

- DownStream (DS): Forward Region
- UpStream (US): Side & backward region (including caps)

Possibly variable longitudinal segmentation:

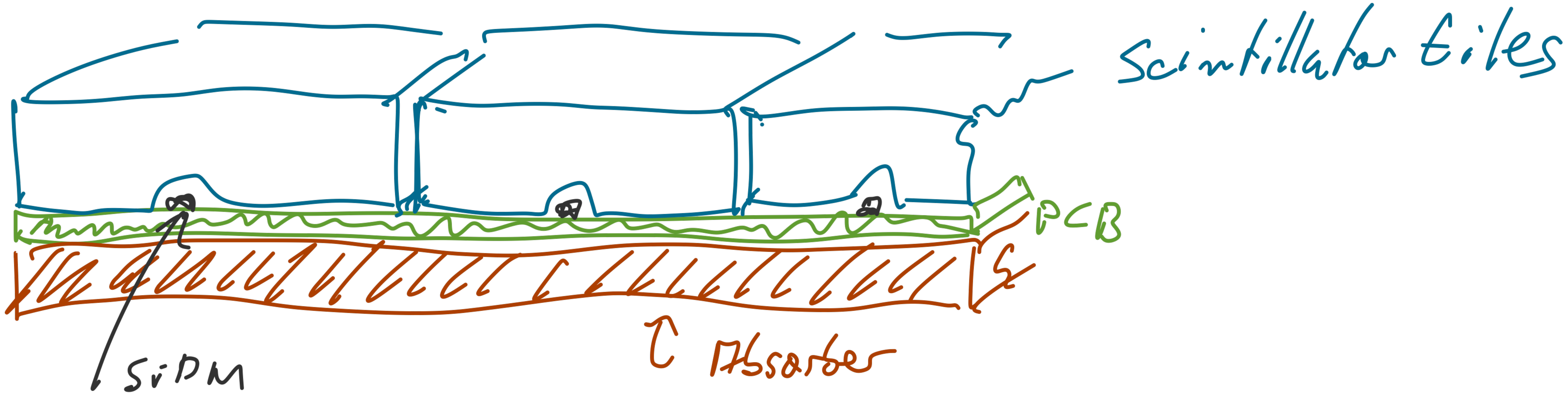
- thin layers in front to enable good energy resolution for low-energy photons
- thicker layers in the rear to ensure sufficient containment with a compact detector



Technology Choices & Options: Baseline

(Partially) based on CALICE AHCAL

- High granularity readout planes: scintillator tiles



one SiPM per tile

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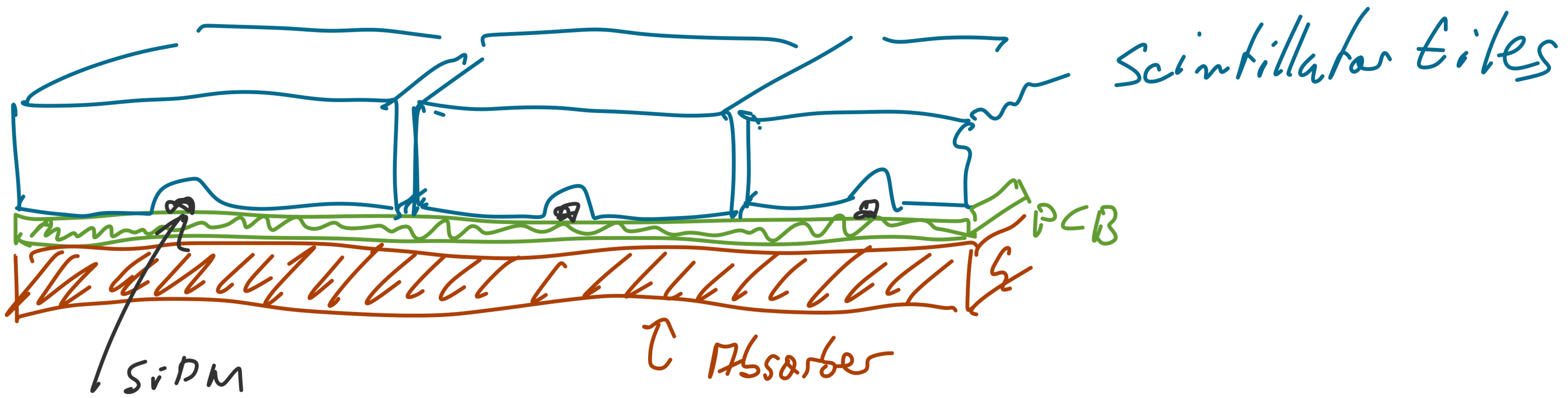
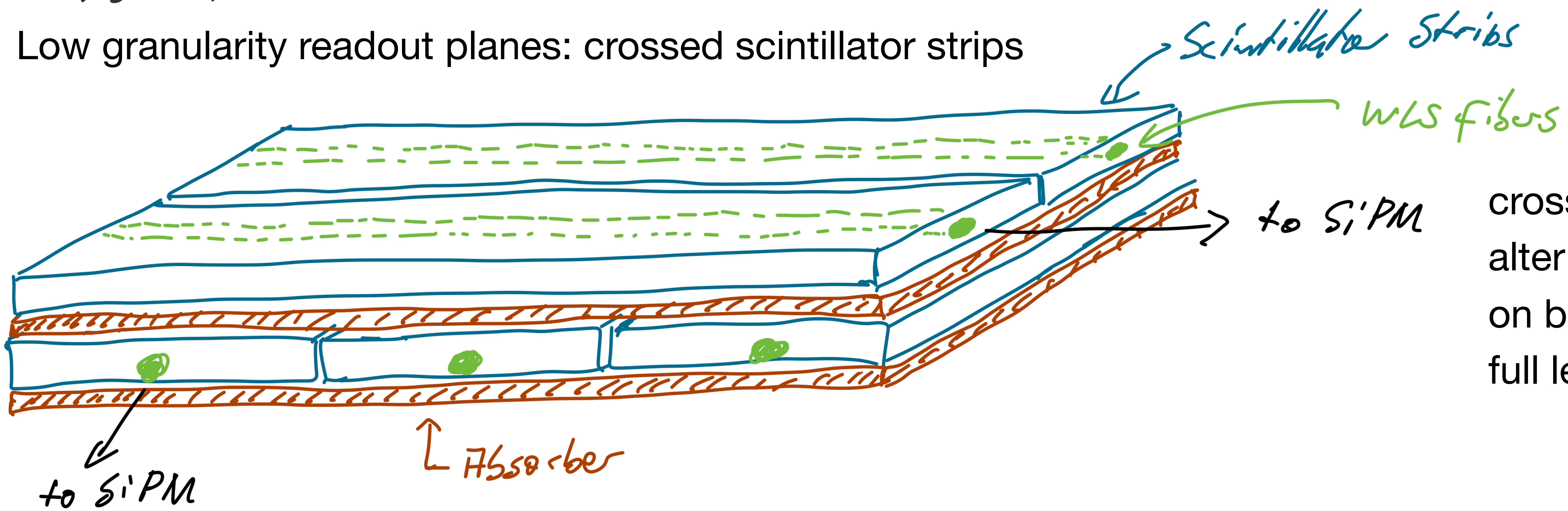


one SiPM per tile

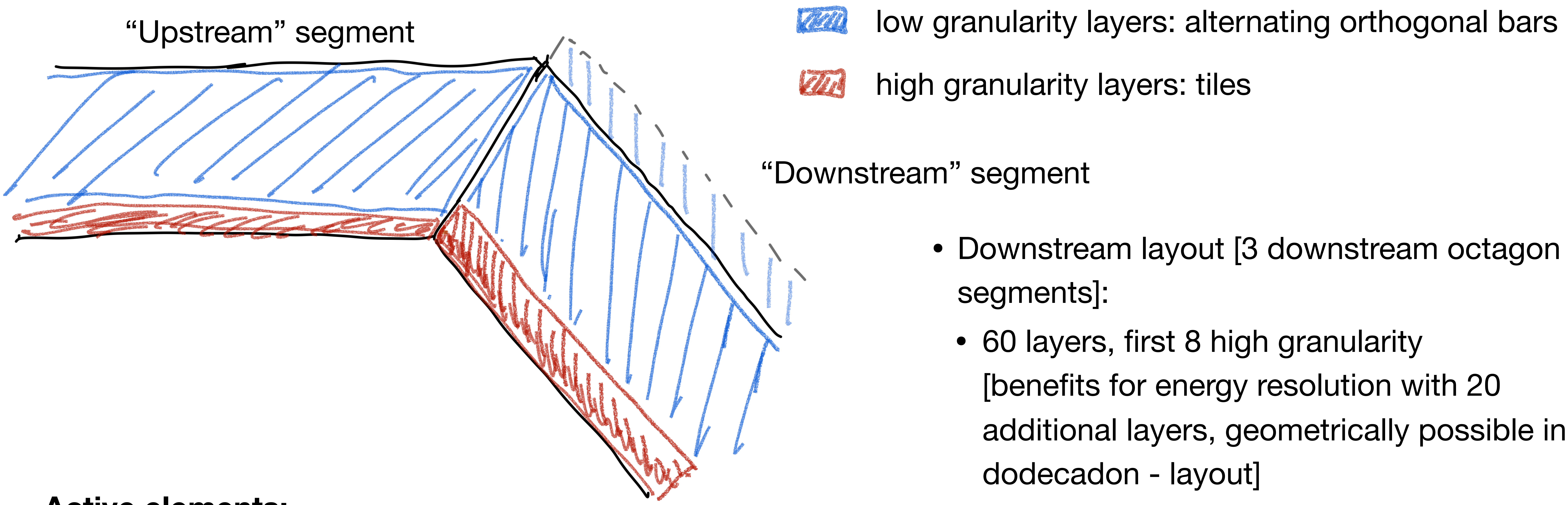
- Low granularity readout planes: crossed scintillator strips



crossed strips in alternating layers, read out on both sides (strips span full length of segment)

The Current Detector Model

A starting point - likely not what would get built



- 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

ECAL Cost

- CORE Cost (incomplete - missing production / installation tooling, yield, off-detector systems & services,…)
- Mainly a spreadsheet exercise between Eldwan and myself
  Based on:
  - Cost information from Belle II, CMS HGCAL, CALICE AHCAL & TCMT
  - Educated guesses & rough estimates

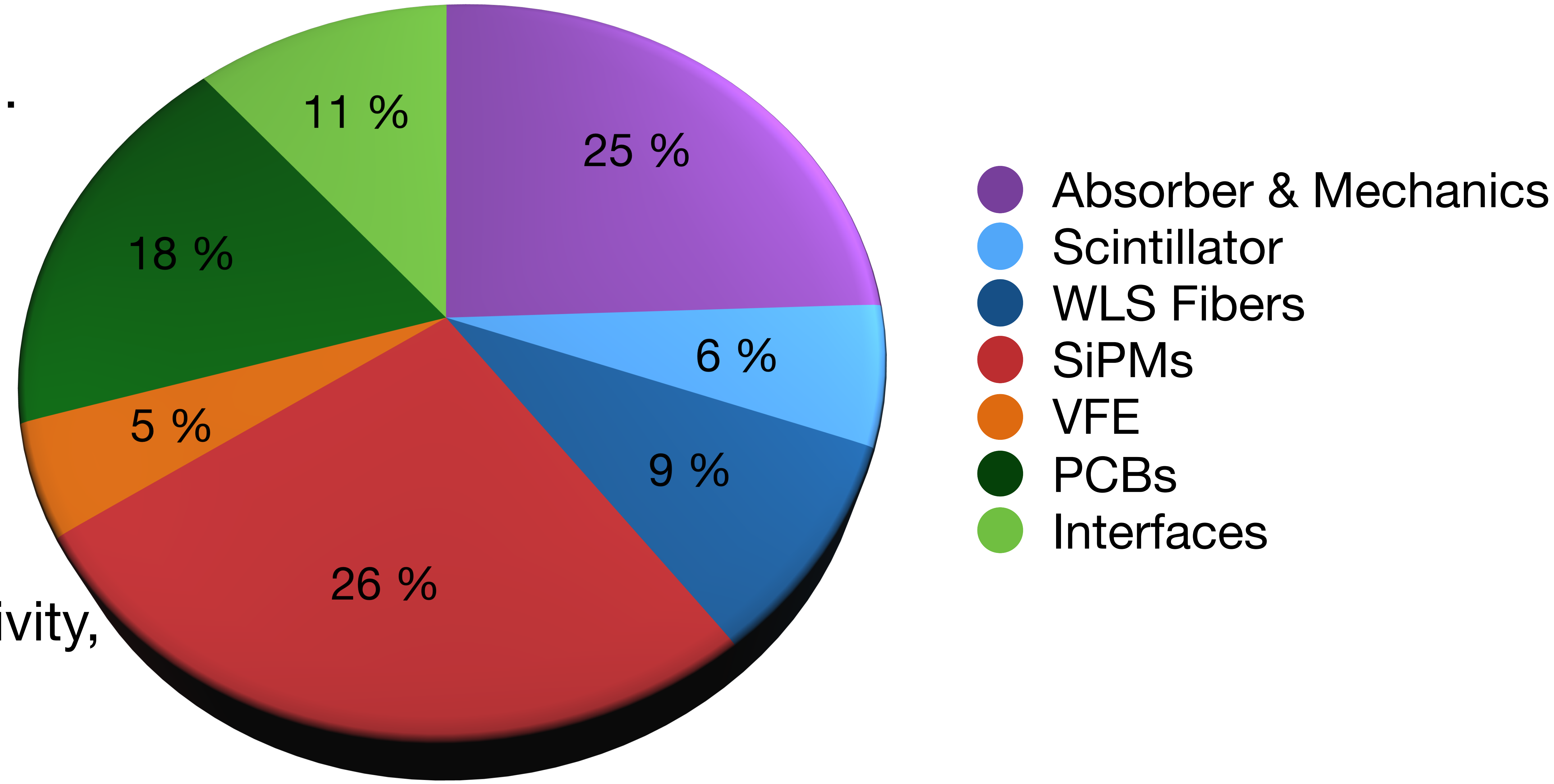
Not even preliminary - to be taken with a large grain of salt, primarily as a discussion starter

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

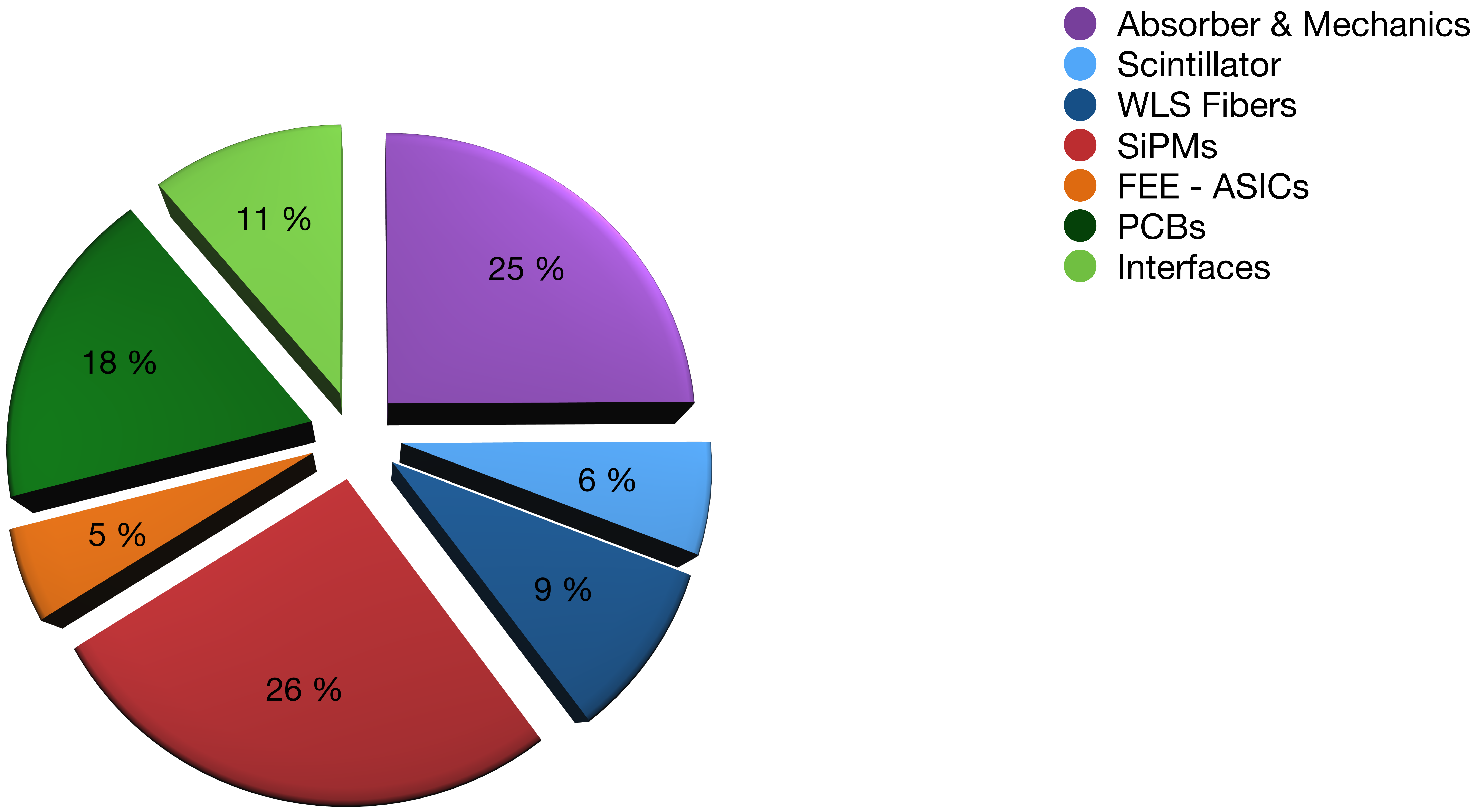


- Channel count the main cost driver - clearly need to understand how much is needed / can be justified (*also remarked by LBNC*)

➯ 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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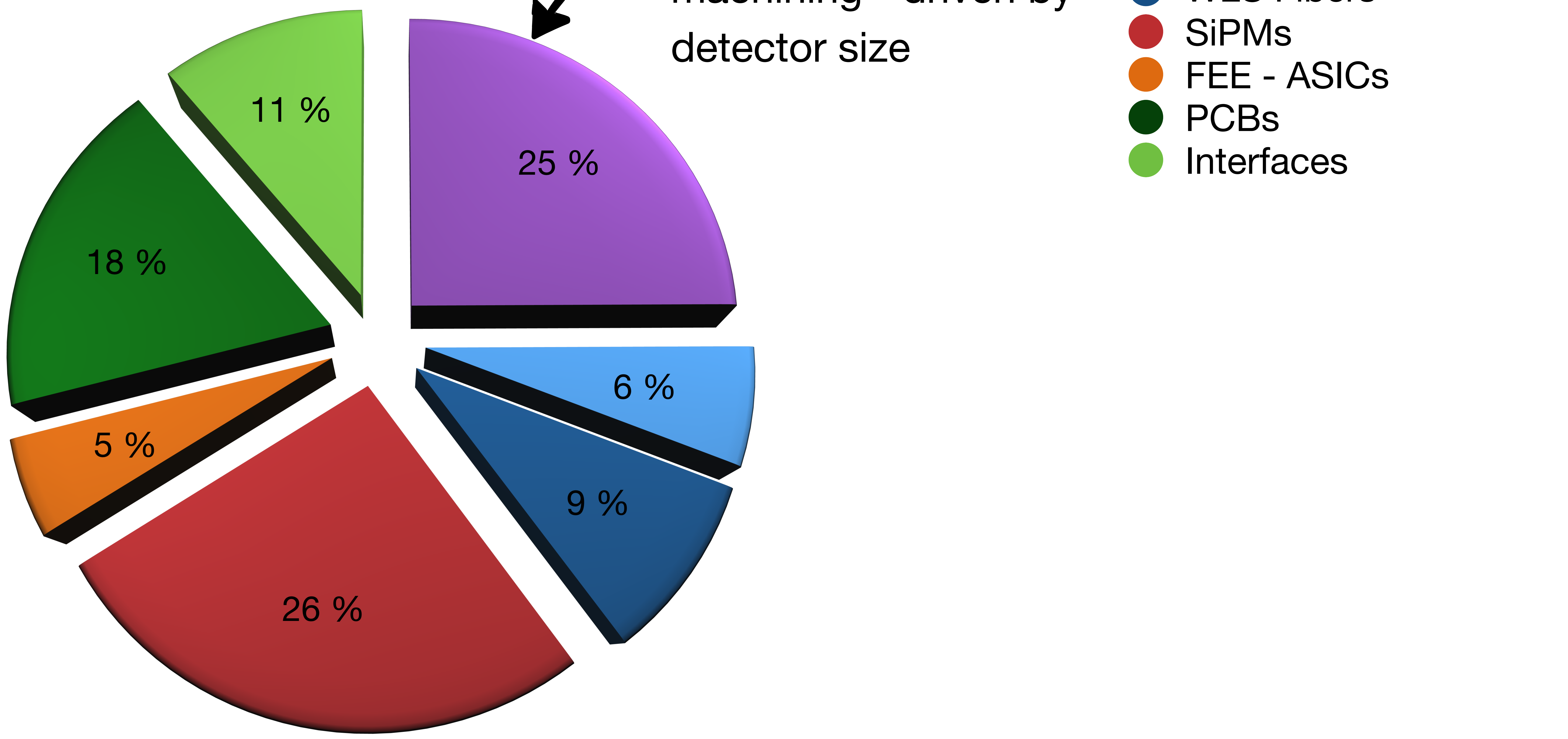
Zooming in on scaling expectations

material costs + machining - driven by detector size



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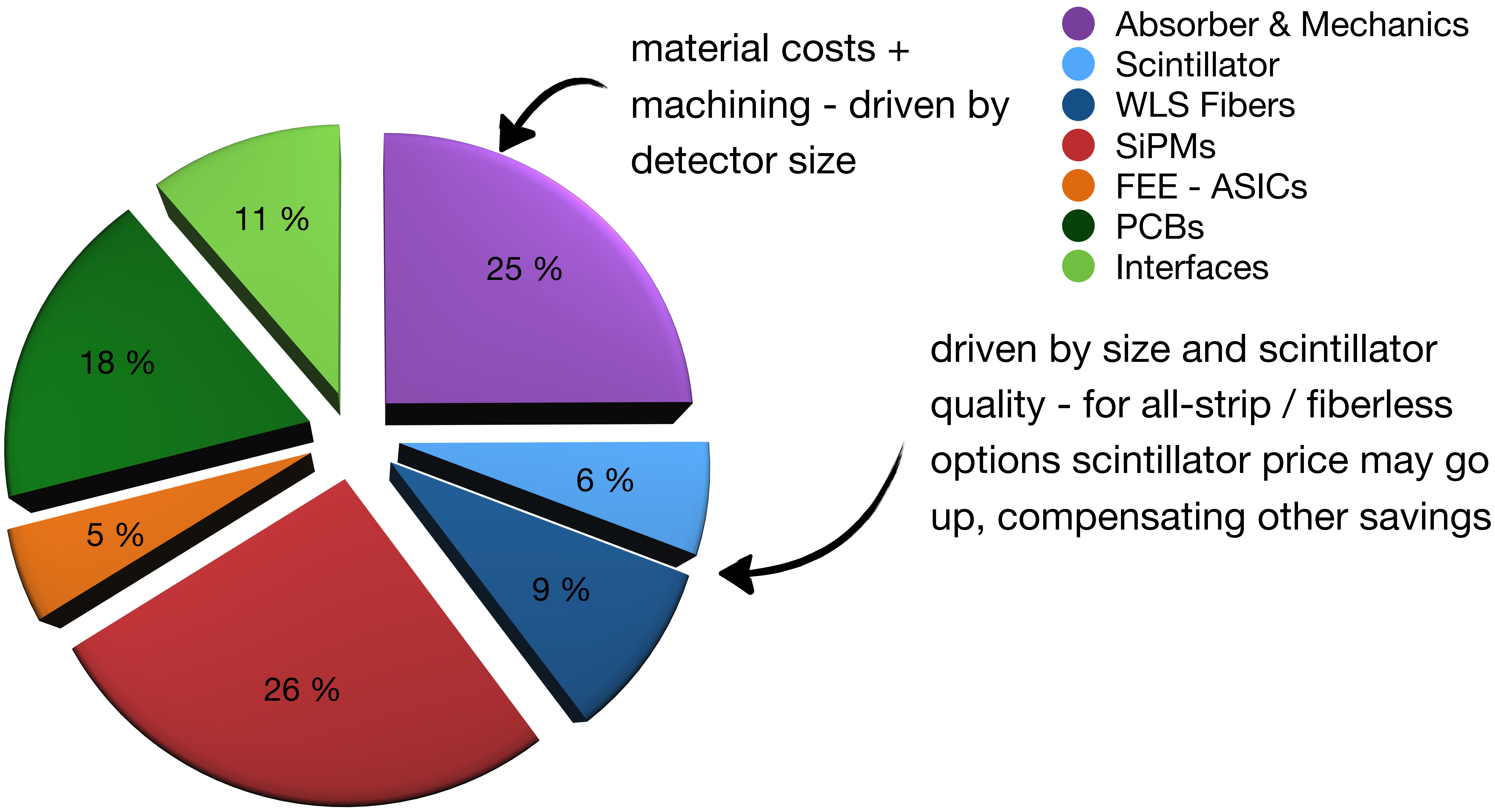

driven by size and scintillator quality - for all-strip / fiberless options scintillator price may go up, compensating other savings

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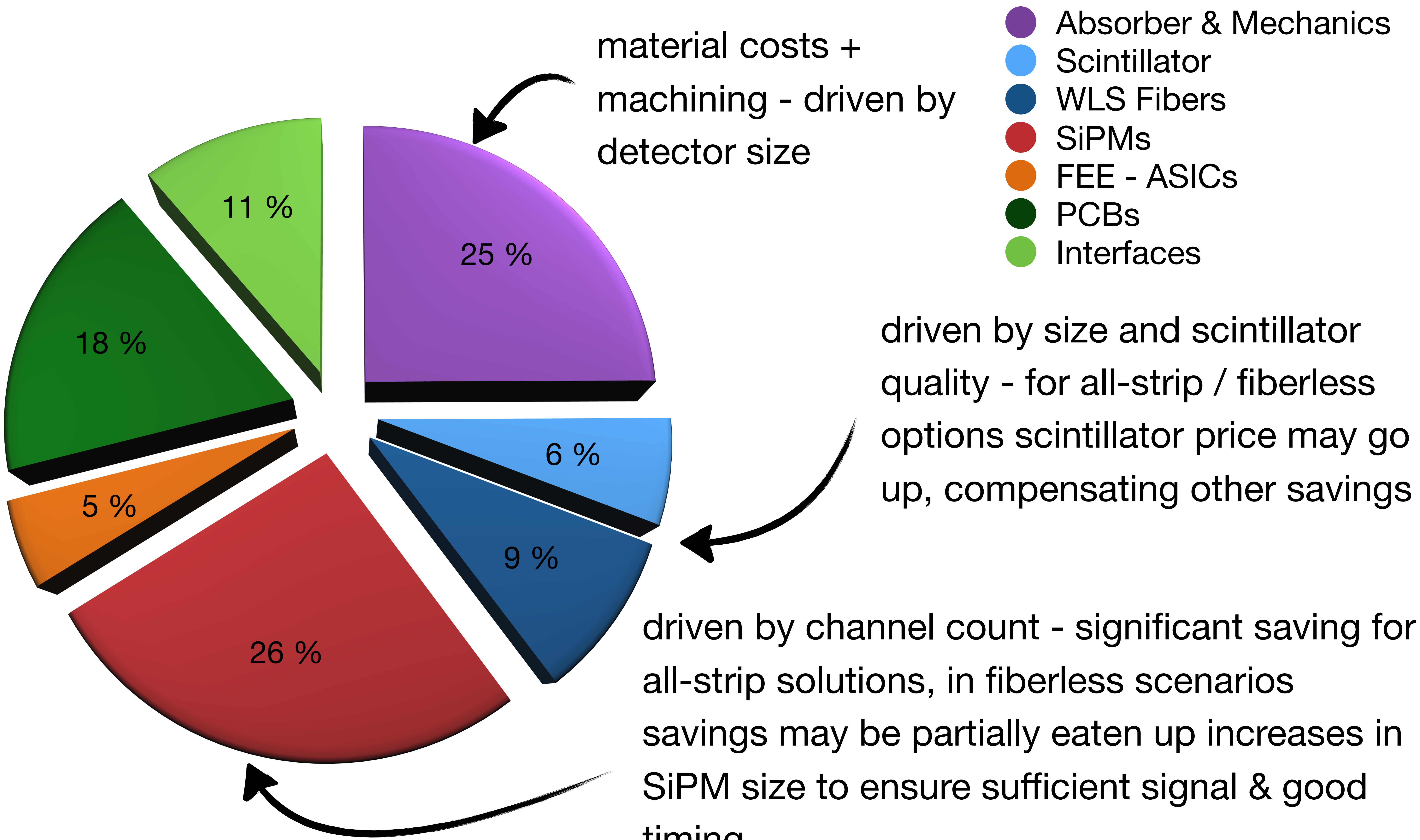

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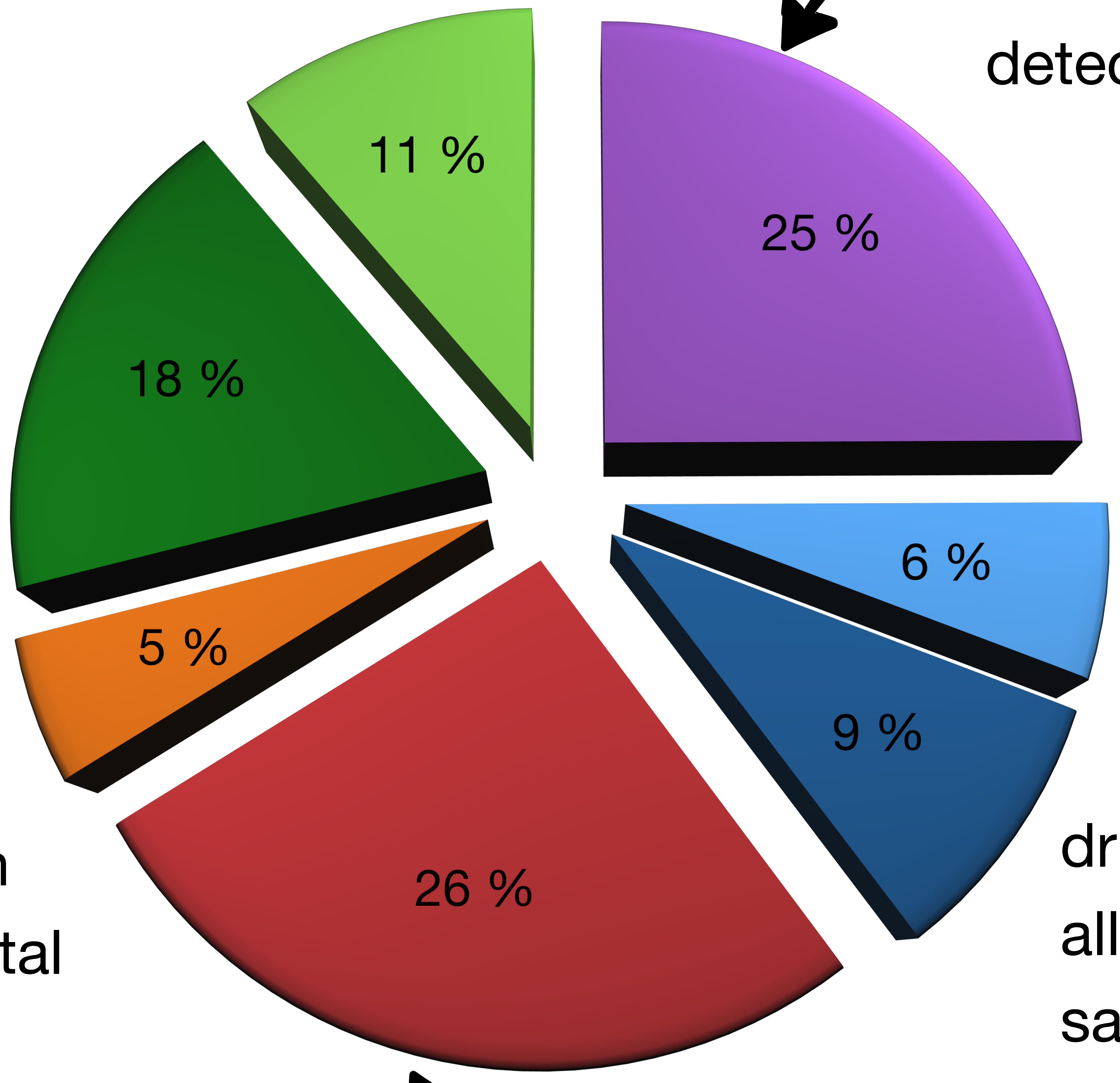

- Absorber & Mechanics
- Scintillator
- WLS Fibers
- SiPMs
- FEE - ASICs
- PCBs
- Interfaces

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ASIC + associated costs driven by channel count + cost pedestal

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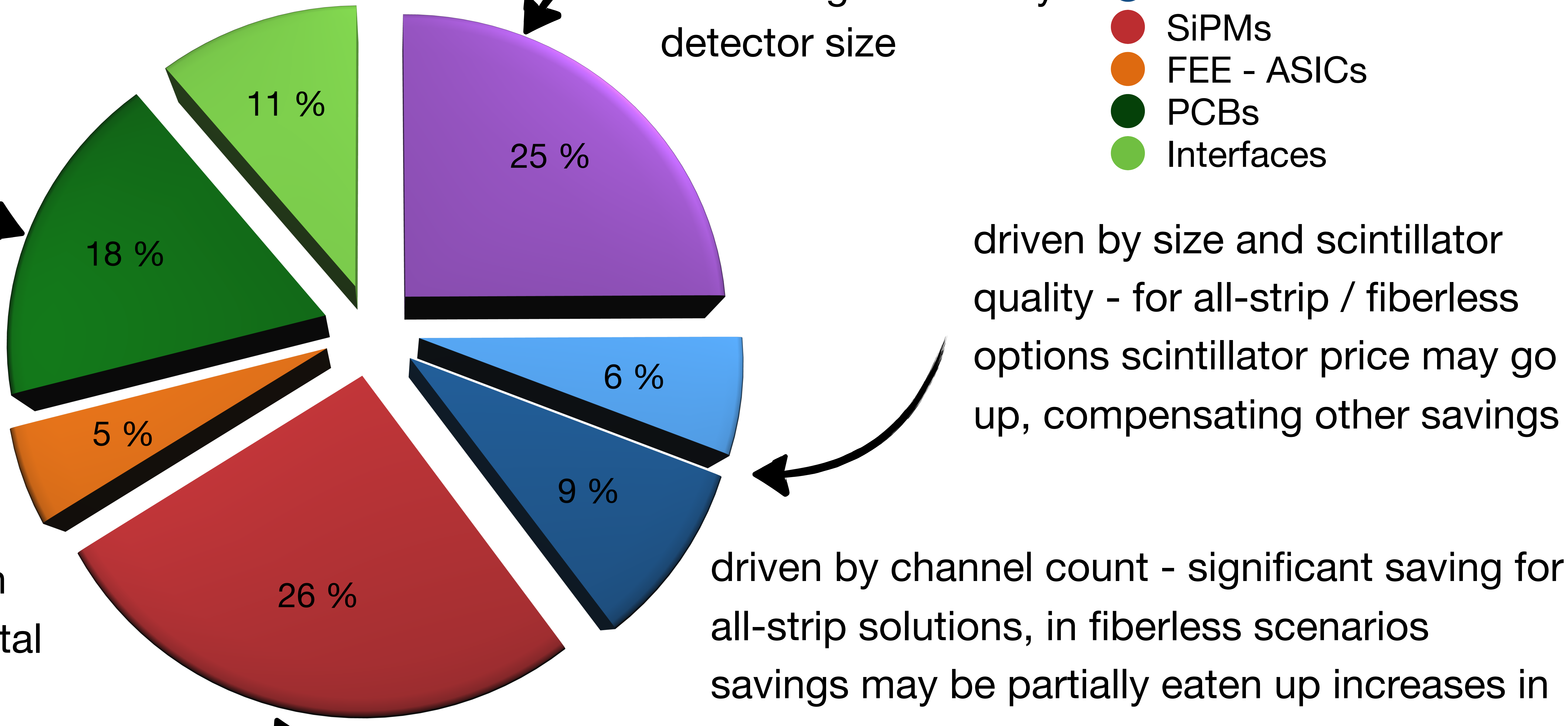

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PCB for HG elements - driven by area (= number of layers) of HG elements

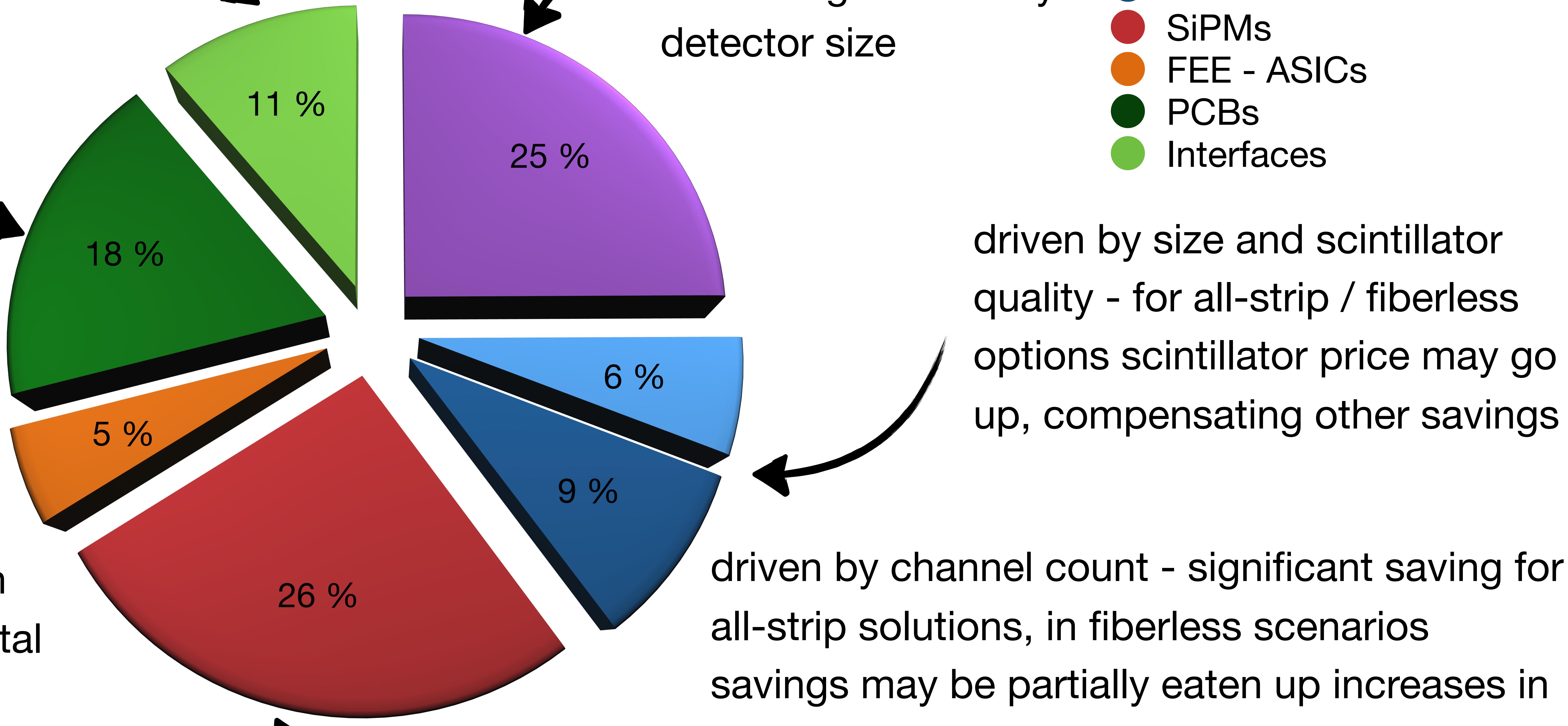
ASIC + associated costs driven by channel count + cost pedestal

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

material costs + machining - driven by detector size



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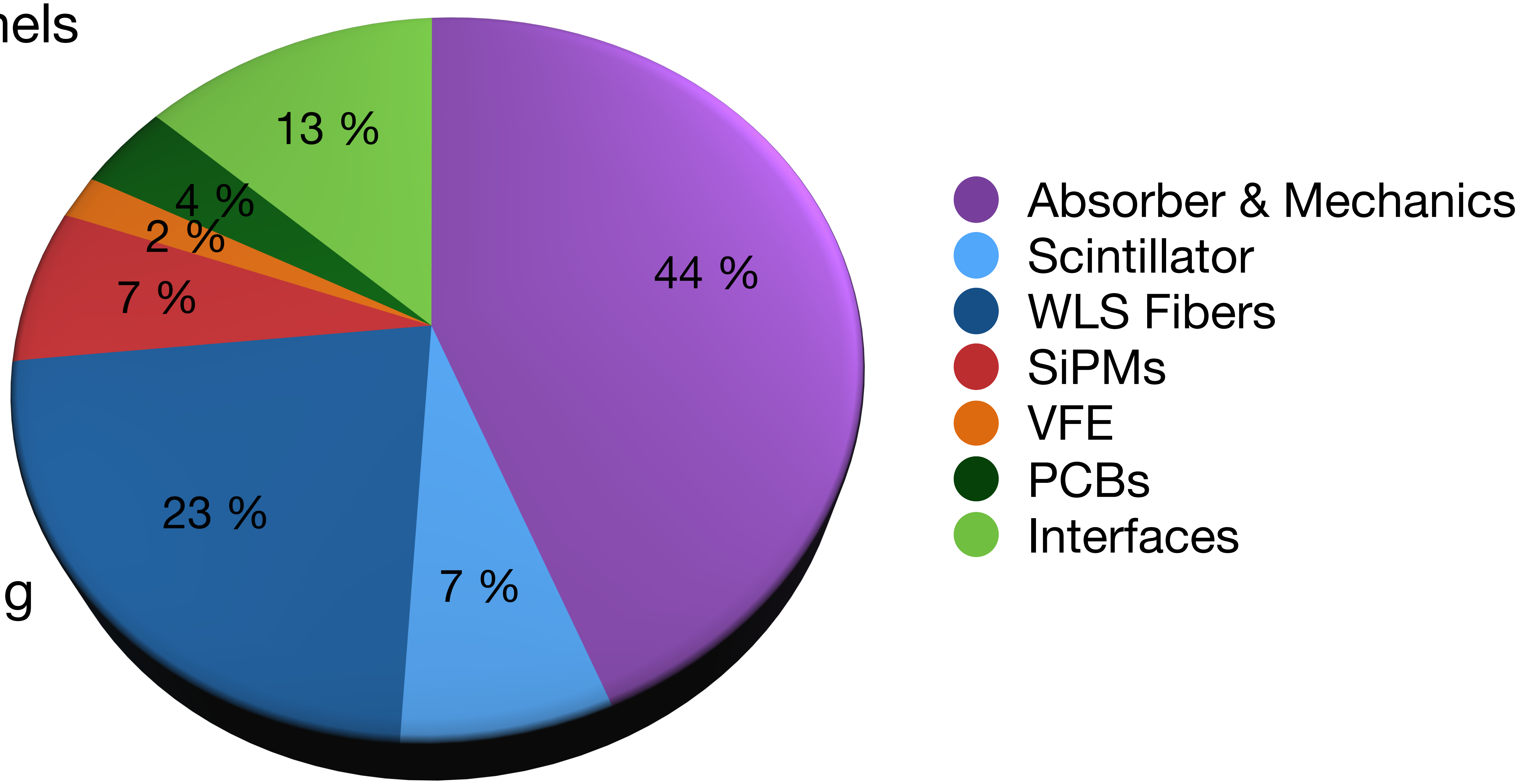
Cost: Strips Only

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

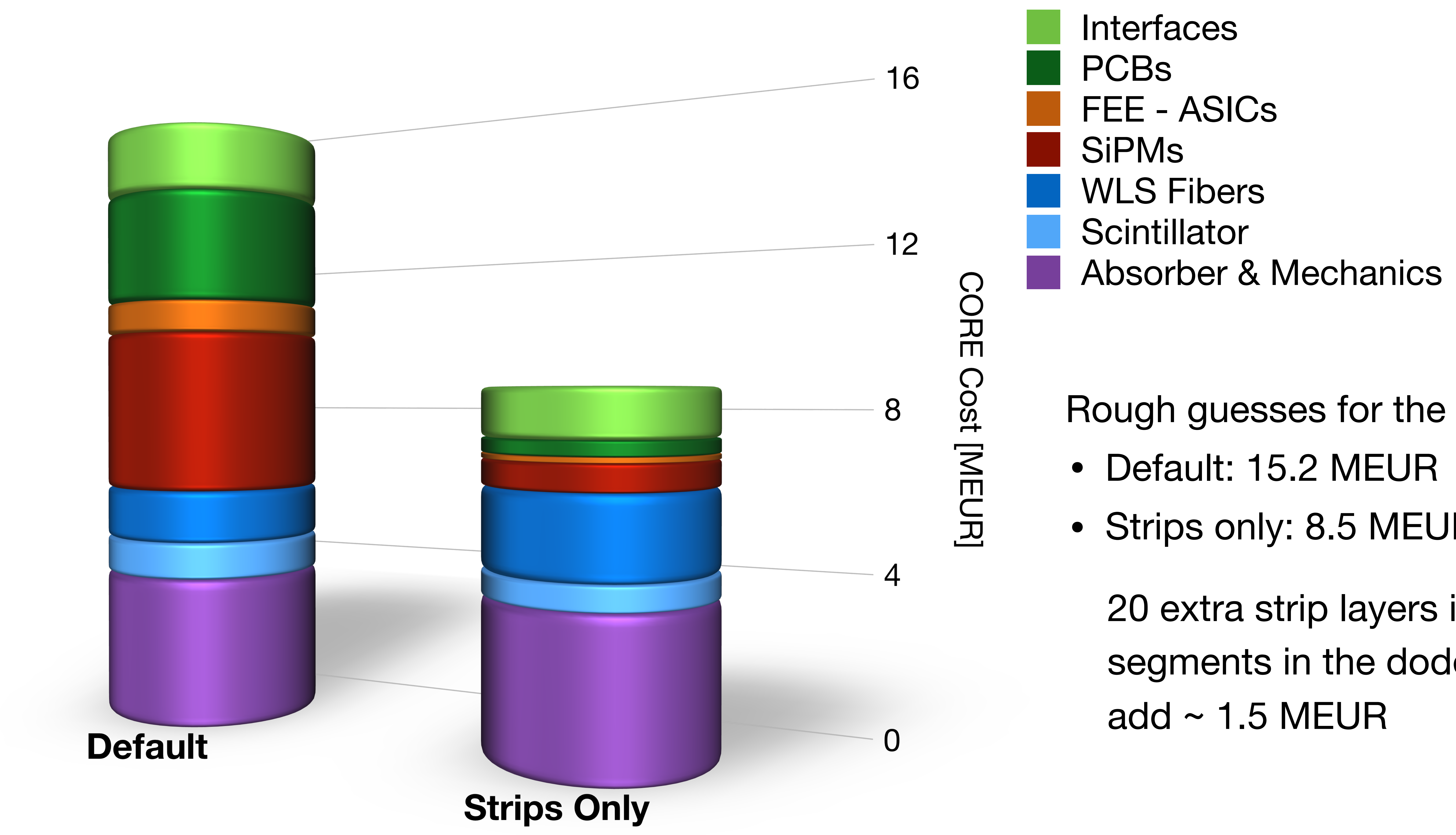
- Lengths, Areas & Volumes:
  - ~ 29 m^3 absorber (when using Cu)
  - ~ 73 m^3 scintillator
  - ~ 480 km fibers
  - ~ 210 m^2 PCB for SiPM / strip & ASIC coupling



- 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

R&D Items

- Only a few ideas - many possibilities exist

Rethinking the Strip Solution

A possible alternative - capitalizing on timing

- Scintillator strips with embedded wavelength-shifting fibers a “standard technology”, but:
  - Fibers have a negative impact on timing
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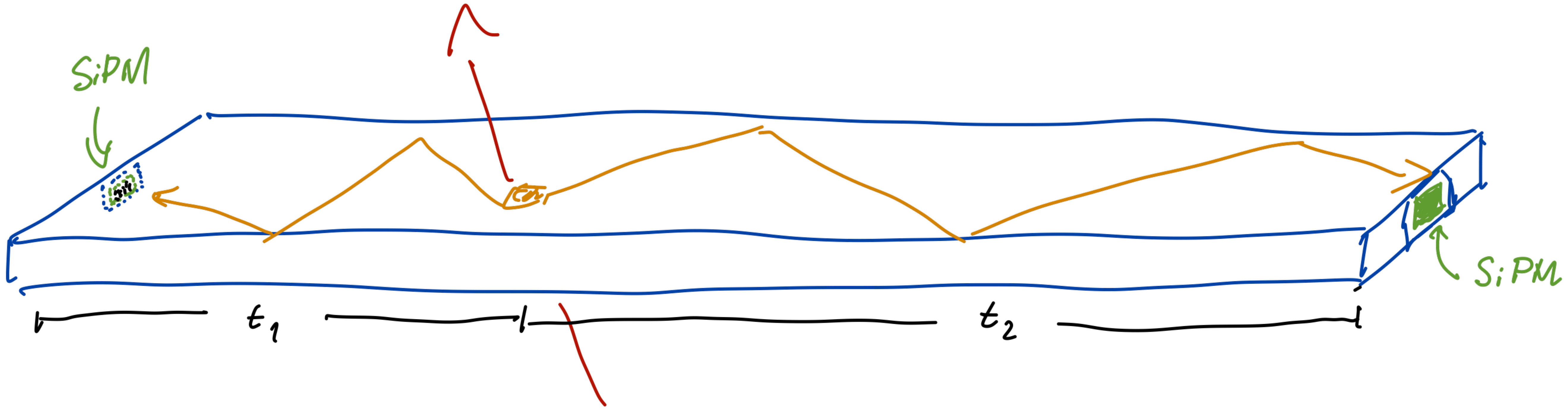
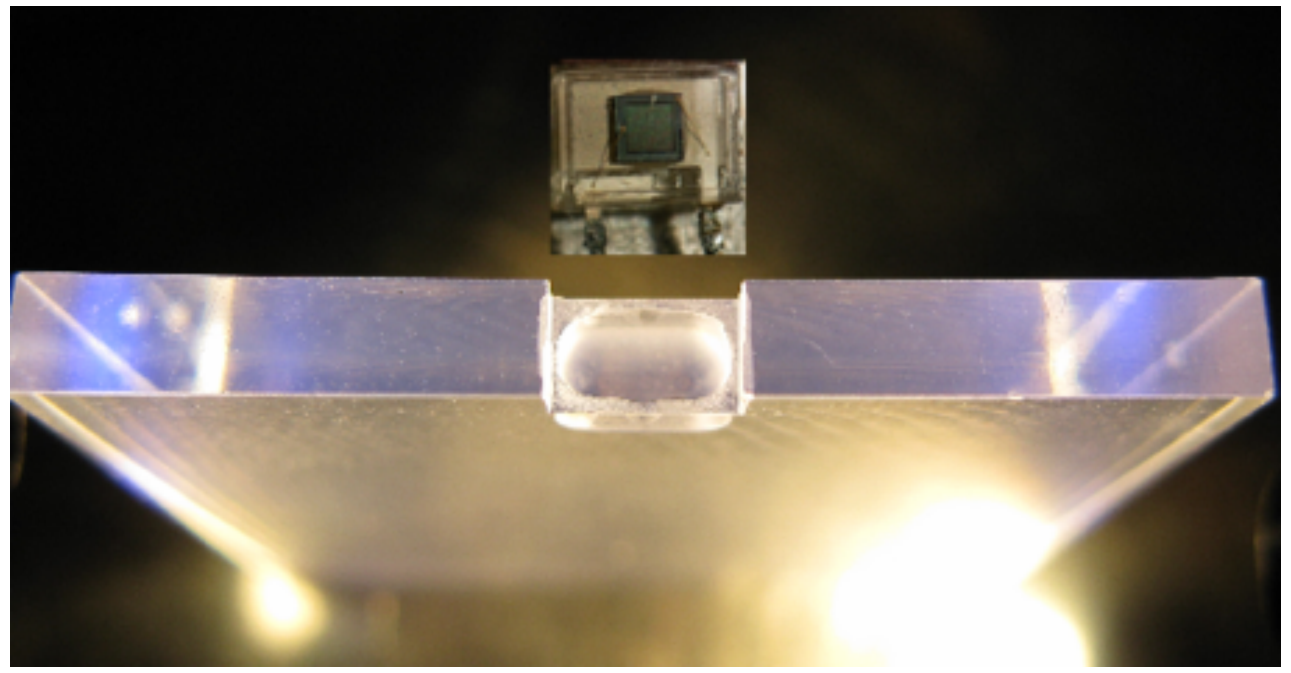
➯ Consider strips with direct readout at both ends - position resolution within strip via timing
  - May require a larger SiPM for increased light yield: Offsets cost advantage of eliminating fiber
  - Requires highly transparent scintillator, possibly shorter strips for sufficiently high and uniform light yield



Profit from earlier studies of direct side coupling at MPP



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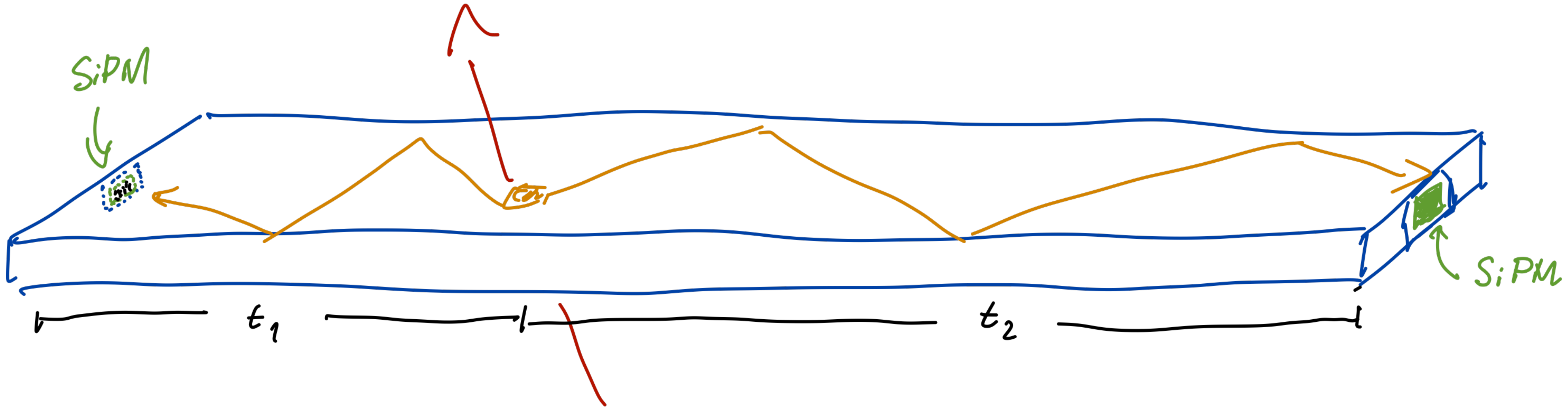

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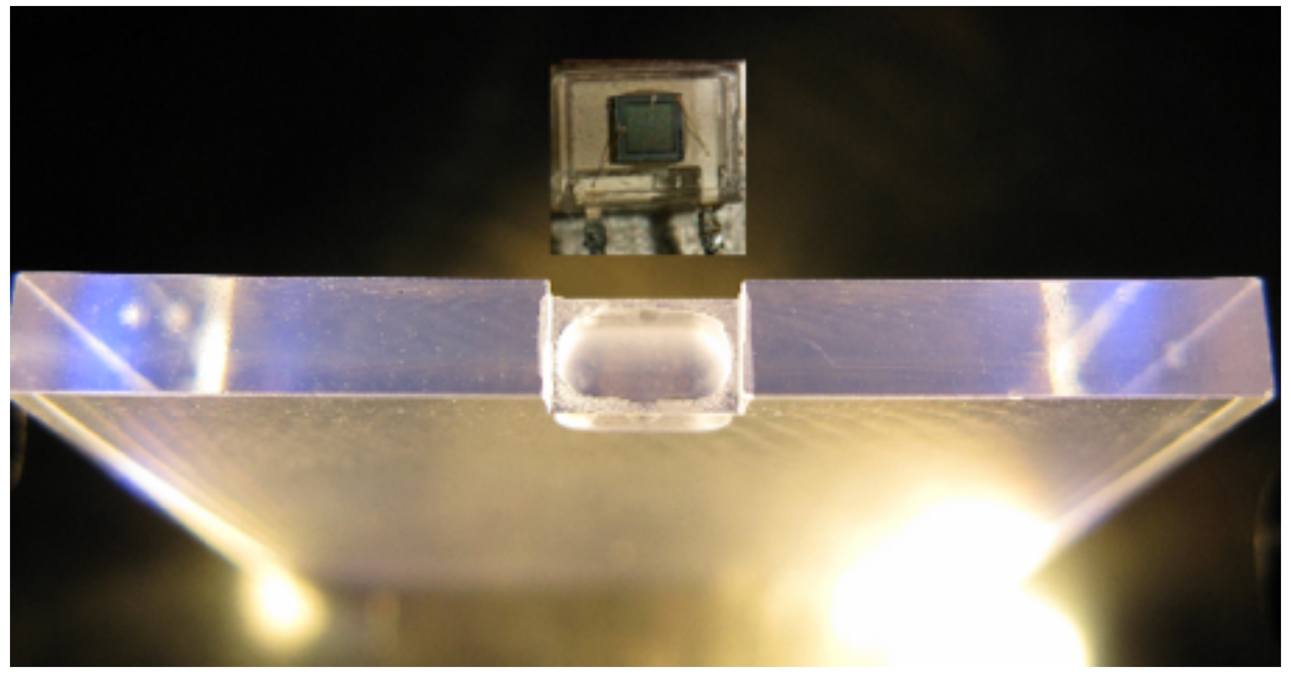


And more general: Advanced scintillator capabilities, such as

- improved neutron sensitivity by doping or coating
- new materials, new production techniques, …

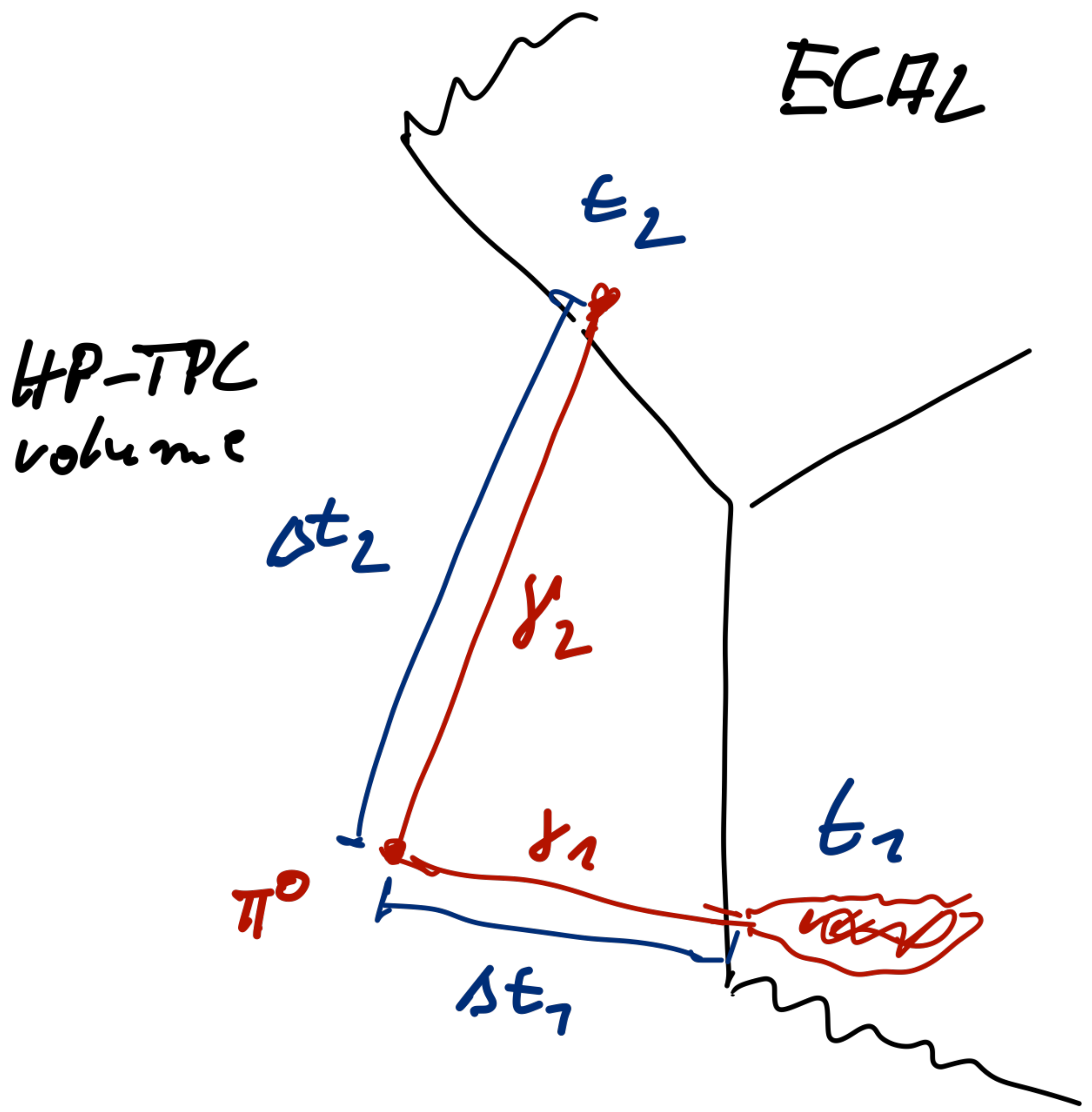
Simulation & Reconstruction

Towards a realistic understanding of capabilities

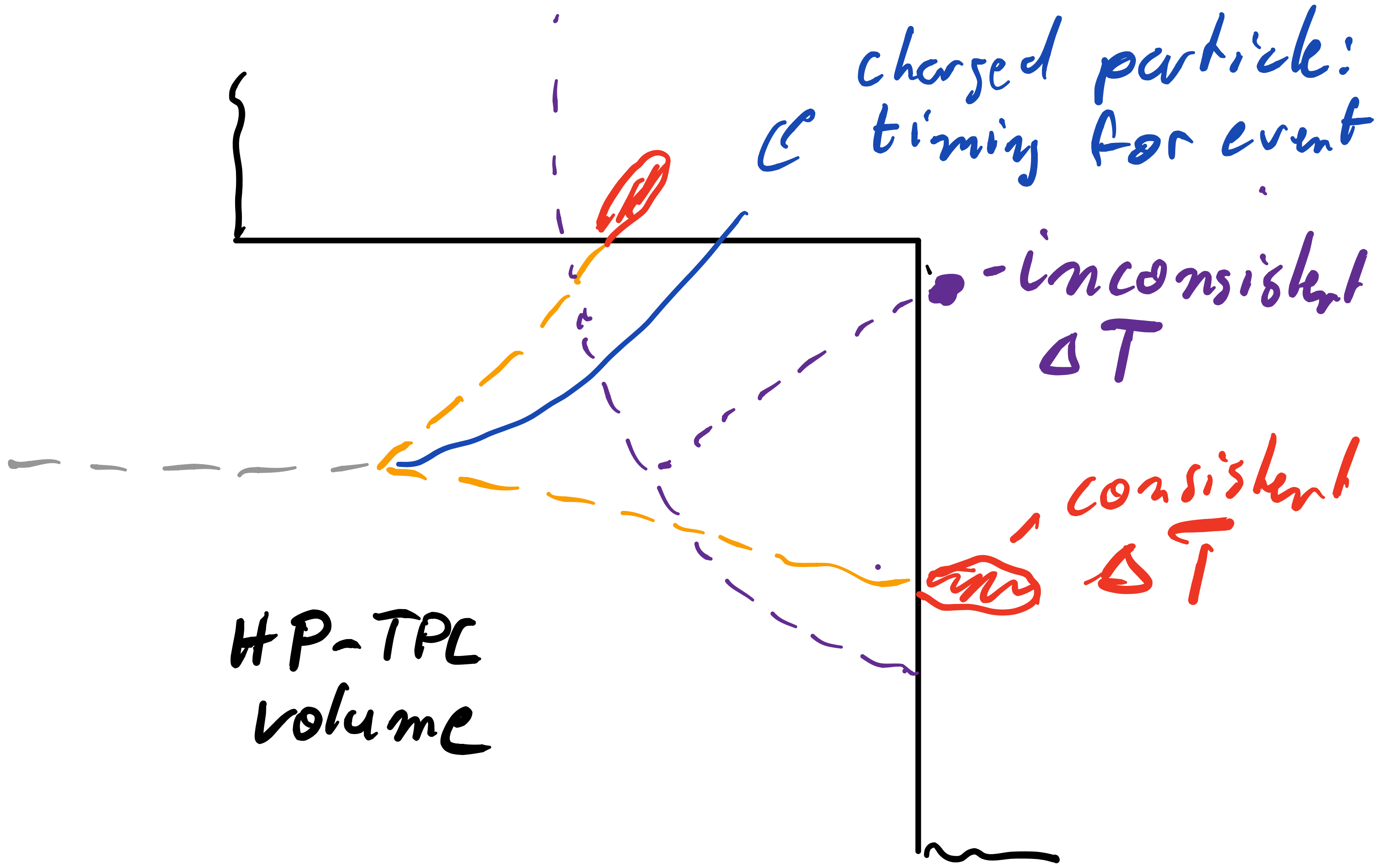
- Understand perspectives for key goals (including neutrons!) in *realistic background environment*
- Further understand / develop reconstruction/ performance of all relevant objects
    - One example: “Timing-assisted π^0 reconstruction”

In first MPP studies:
direction + energy of cluster
(challenging for low energies!)

with few 100 ps timing:
may improve π^0 localization
$\Rightarrow \Delta t_2 - \Delta t_1 \approx t_2 - t_1$



also: general use of timing
in particle association



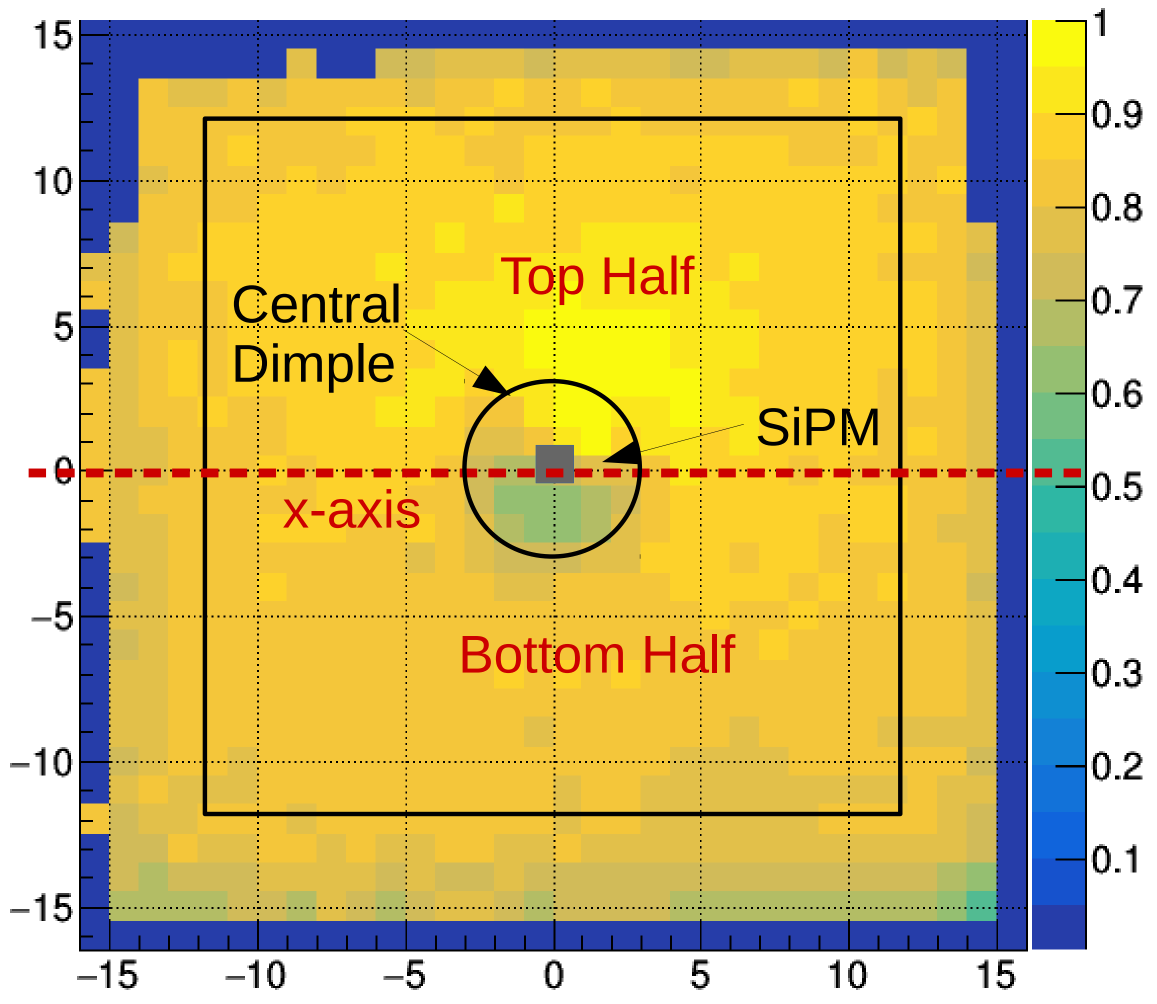
- In general:
    - Need to understand capabilities of tiles vs strips
    - Realistic neutron reconstruction in tile and strip geometries
    - …

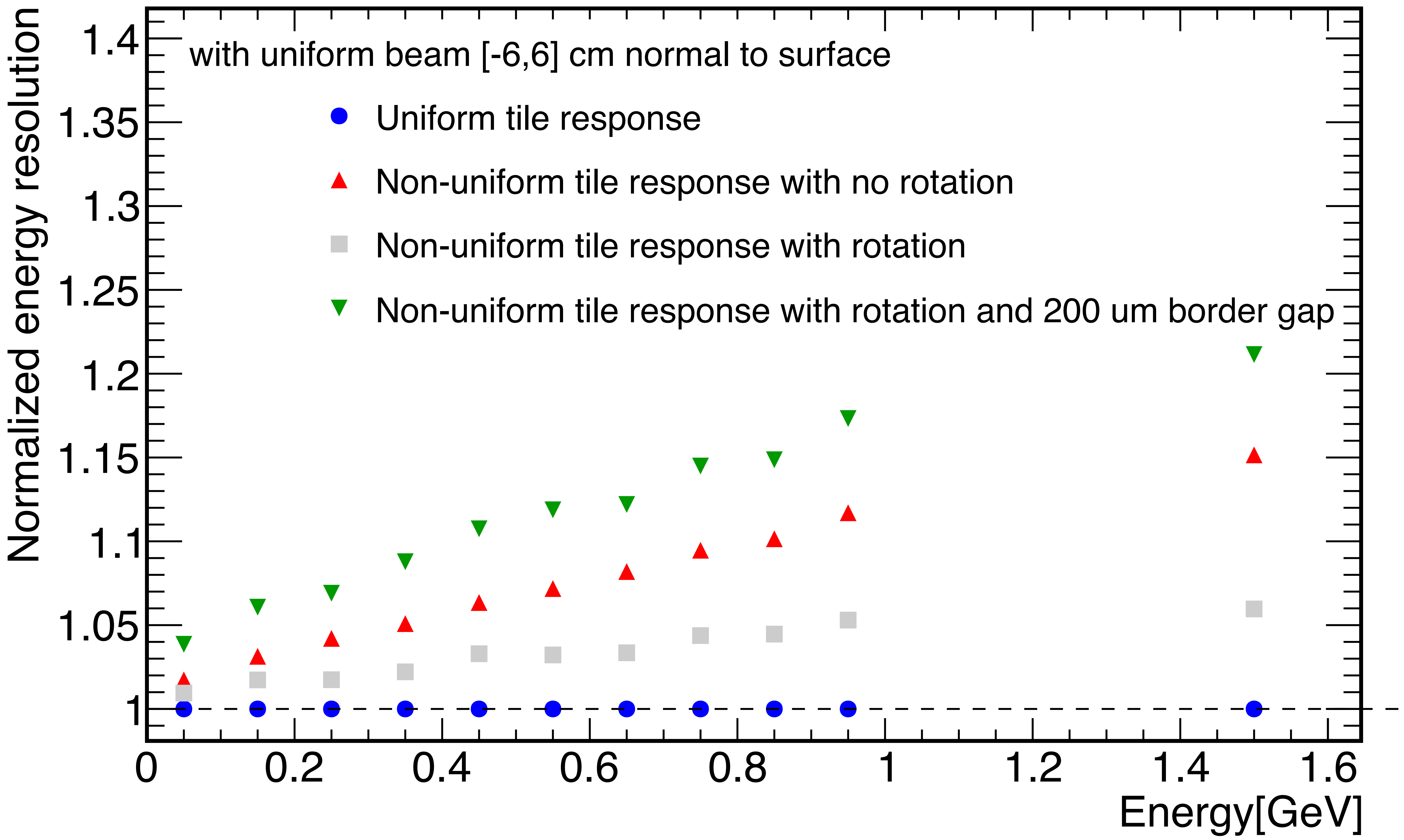
Impact of Realistic Response Uniformity & Tolerances

One example for ongoing studies

- Investigated the impact of tile non-uniformities, gaps between tiles and the material variations due to the ASIC in the on the PCB on energy resolution with a DUNE MPD ECAL - like geometry

  For tile uniformity: Assuming “worst case”, with misalignment of photon sensor wrt the SiPM on the level of ~ 1 mm





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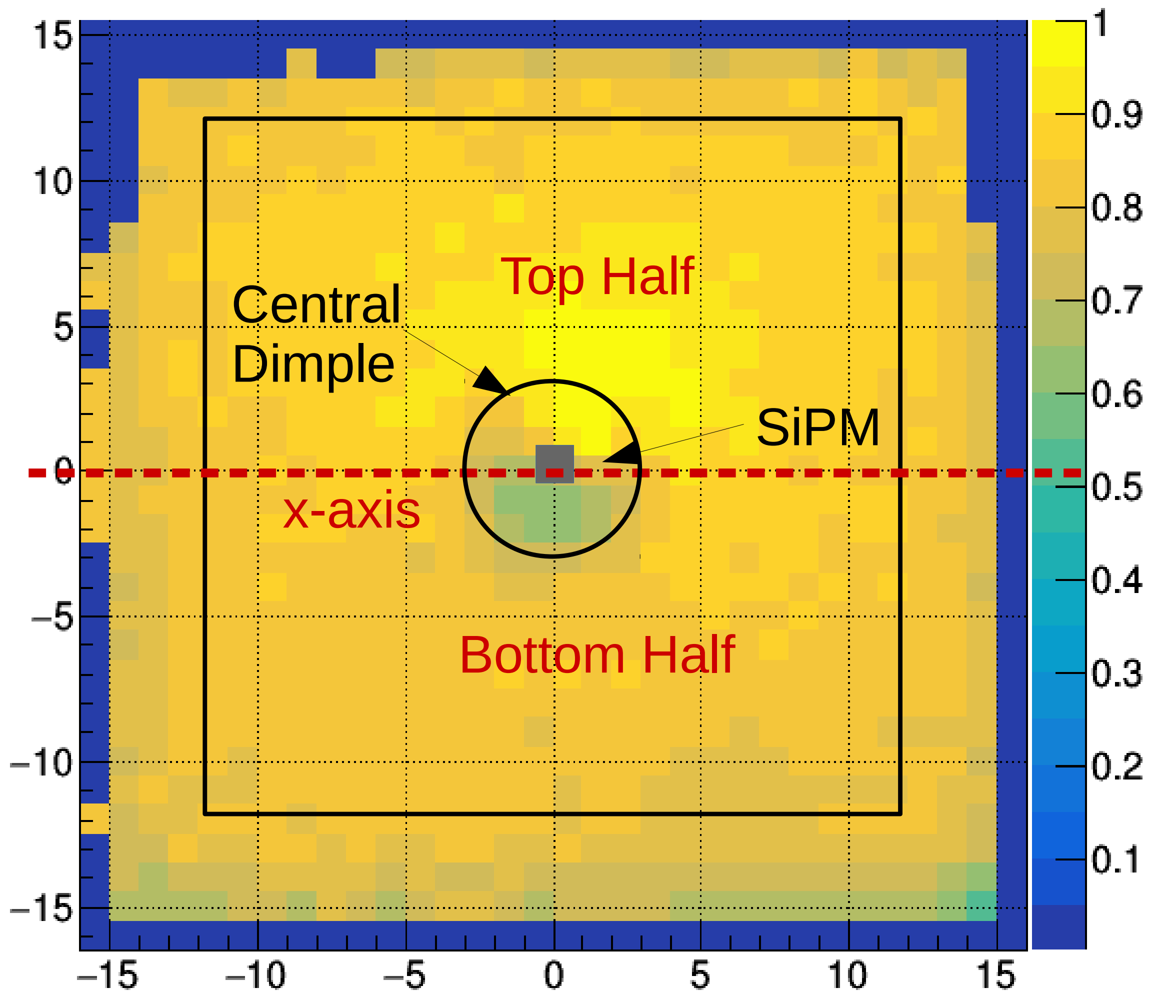
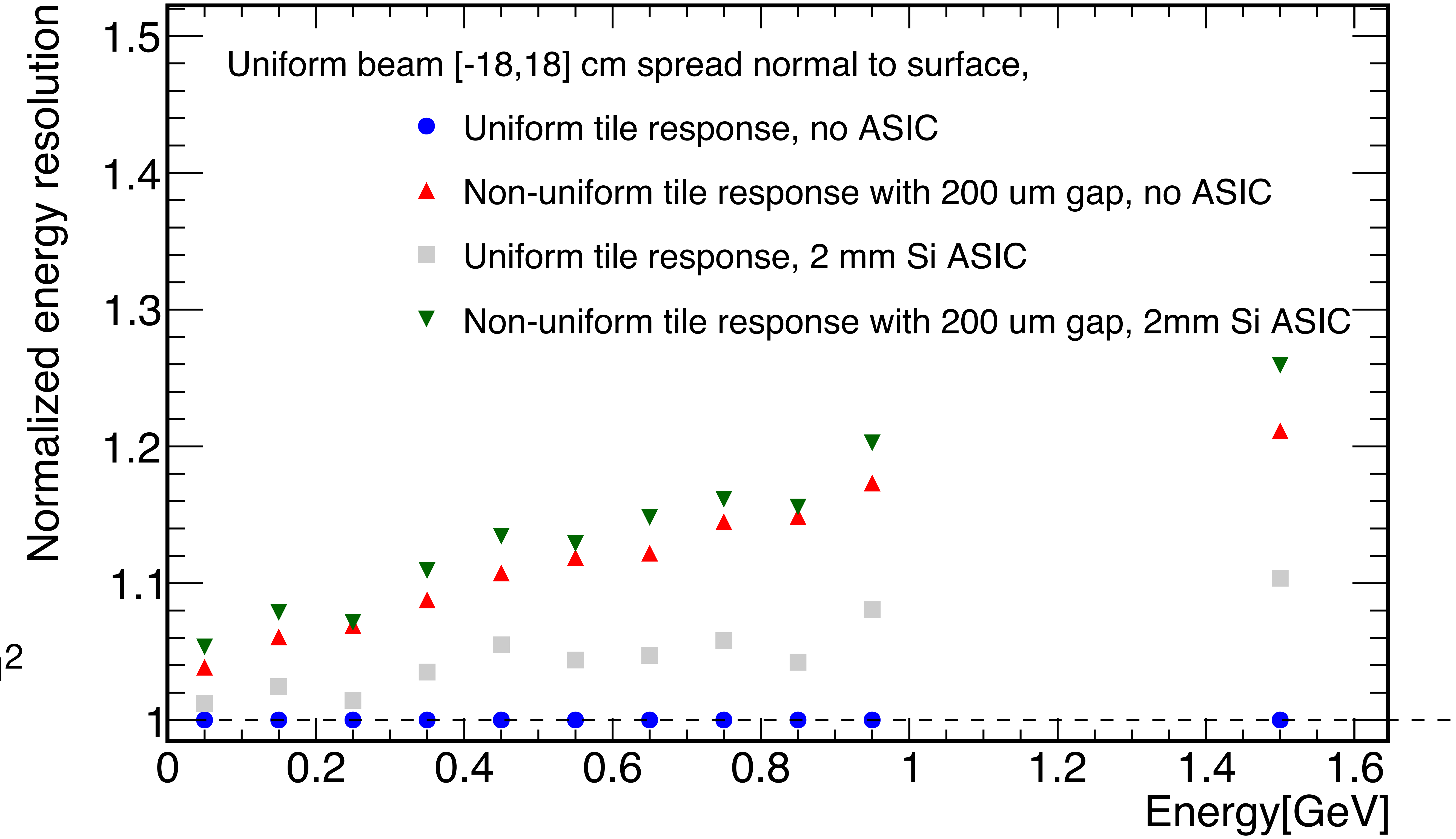


+ a 2 mm thick ASIC covering a few cm²

Globally: Relative impact grows with energy resolution - up to 20% at 1 GeV



Conclusions

and a look forward

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Items to explore, questions to answer:

- Optimise detector design in terms of materials, geometry, …
- Need to understand what features are actually needed to achieve the needed performance
- Need to understand the which aspects of the goals are achievable in a realistic background environment
- Develop reconstruction to get fully realistic performance estimates
- Perform hardware R&D to identify optimal (performance, cost) technological solutions
- Develop realistic engineering design, addressing mechanical constraints
- …