CALICE-style ND ECAL
Detector Concept Status & R&D Questions

Frank Simon
Max-Planck-Institute for Physics

DEEP UNDERGROUND NEUTRINO EXPERIMENT

DUNE Near Detector Workshop
Fermilab, May 2019

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

Outline

- Global detector layout
- Main performance goals
- Technology choices & options
- Cost Drivers
- R&D plans

The Global Layout

Driven by the Dimensions of the HPgTPC

- *Dimensions* of the HPTPC fiducial volume
  - Radius: 2.7 m
  - Length: 5.5 m

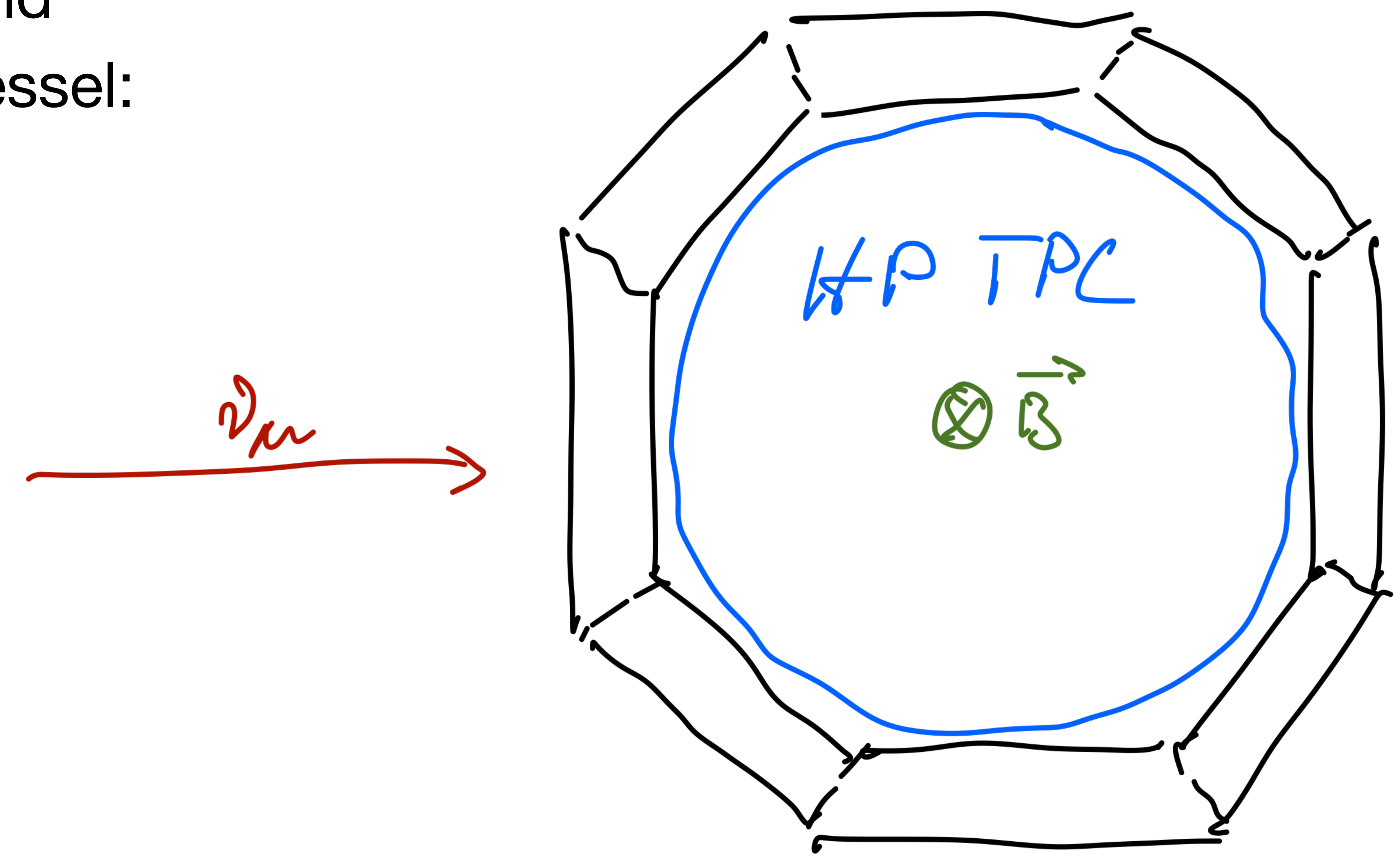
Magnetic field:

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

- 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: An *octagonal* structure

Dimensions:

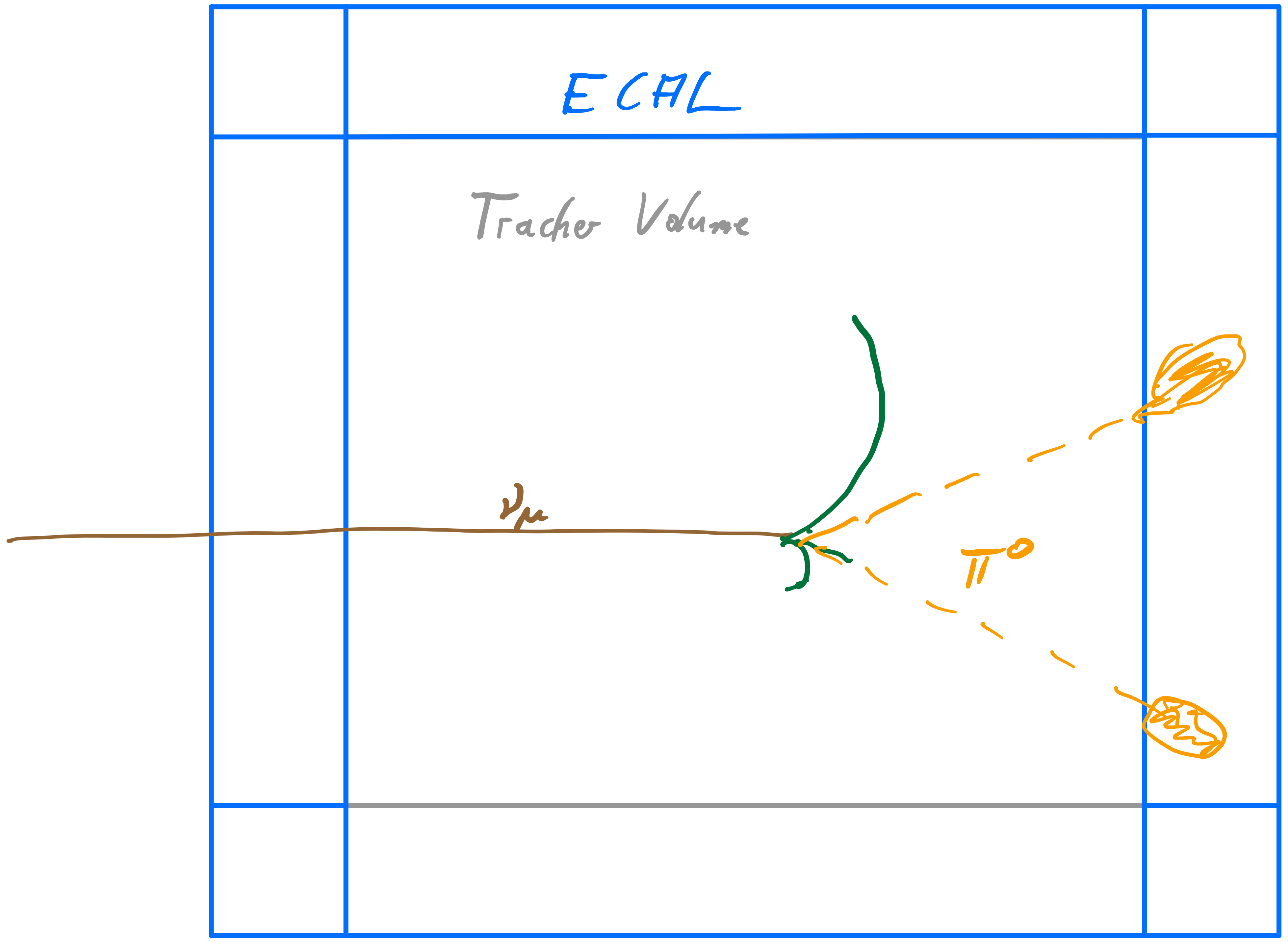
- Octagon side length: 2.25 m
- Barrel inner surface: ~100 m^2
- Cap inner surface: ~50 m^2



Main Performance Goals

Must-haves, ideas & aspirations

- 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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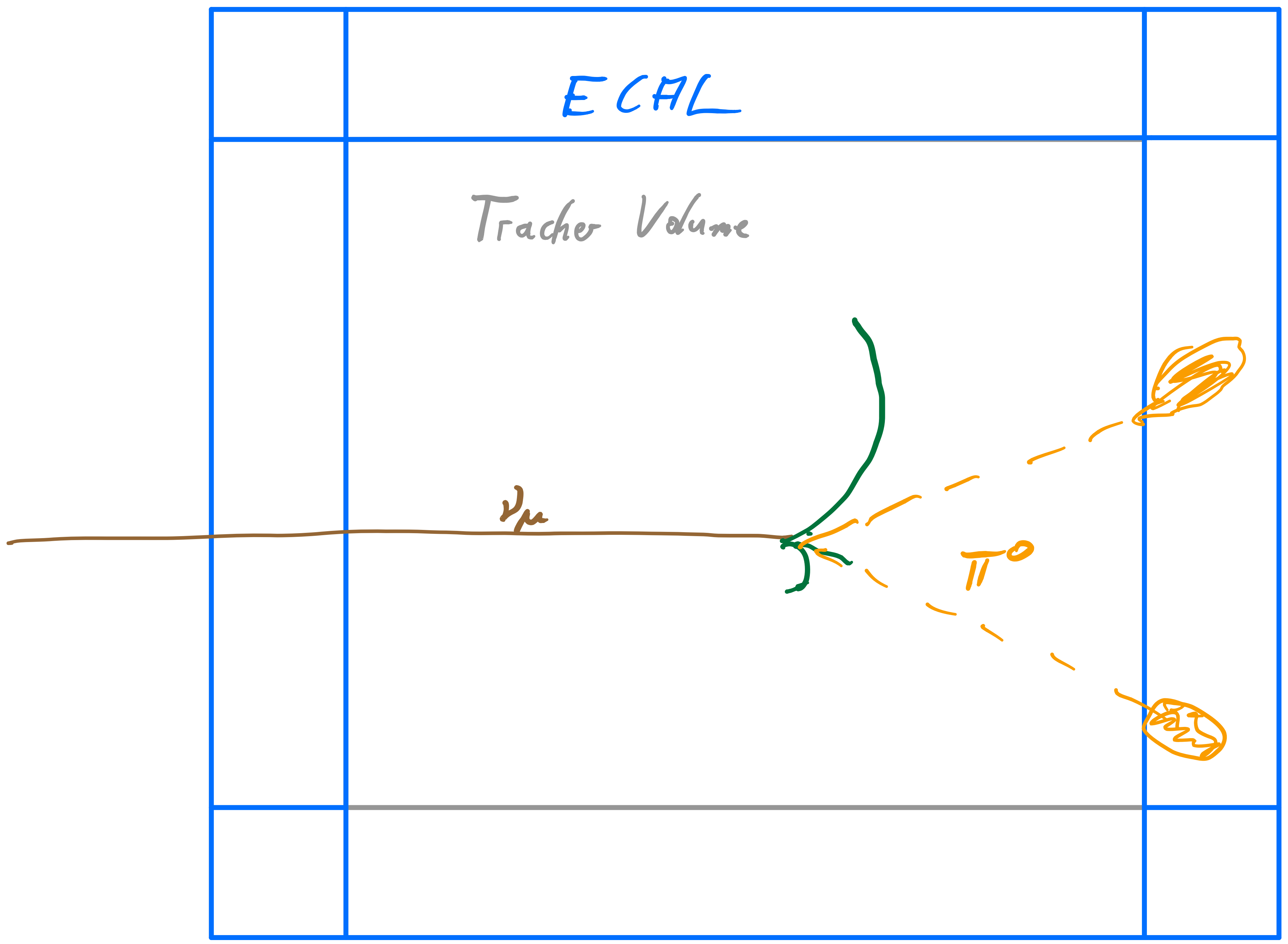
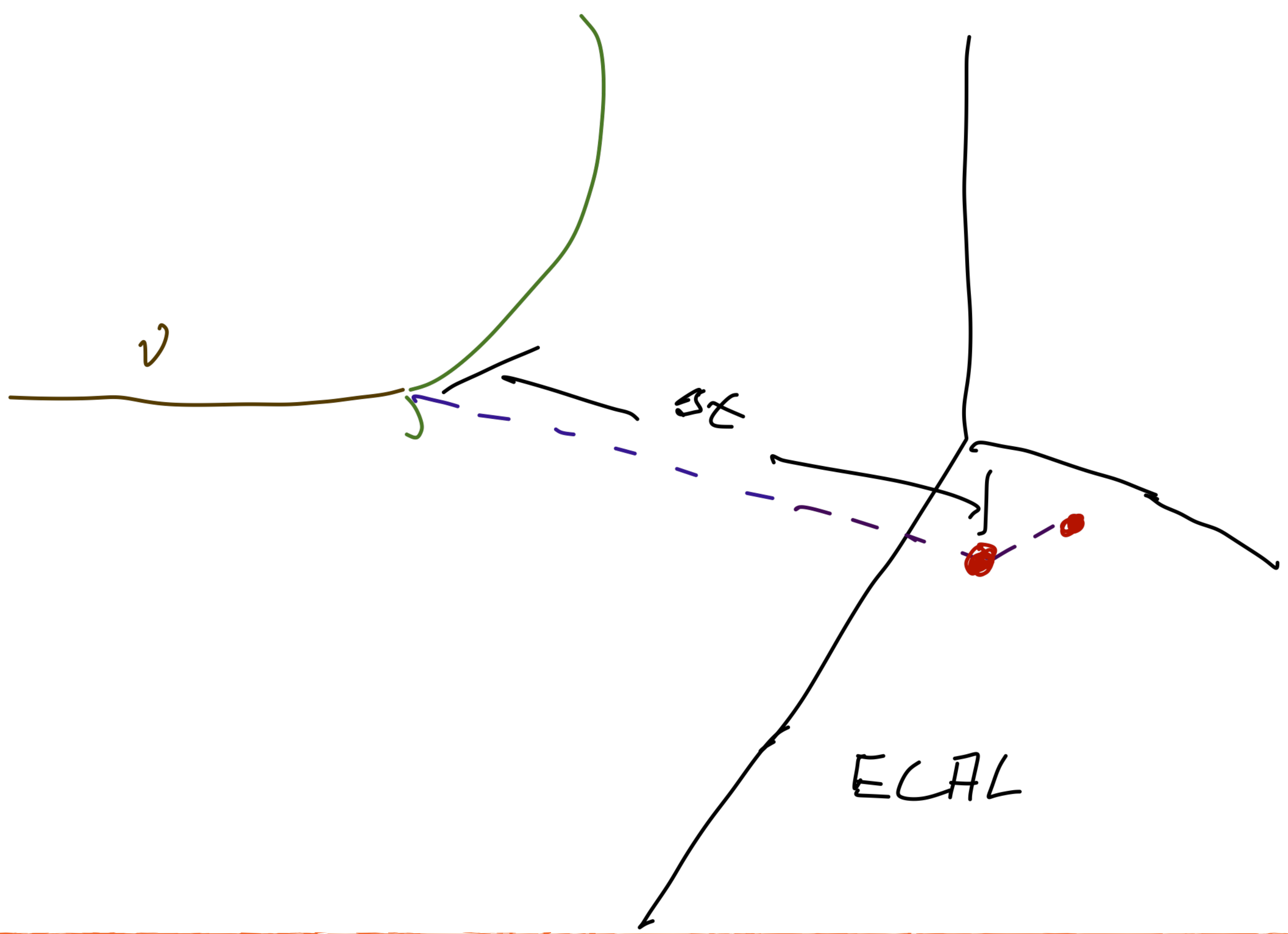


- Neutron reconstruction - a potential game-changer [still needs to be established in realistic environments!]
  - Requires timing on the few 100 ps level to enable energy measurement via time-of-flight



Refining the Design

Accounting for environment and constraints

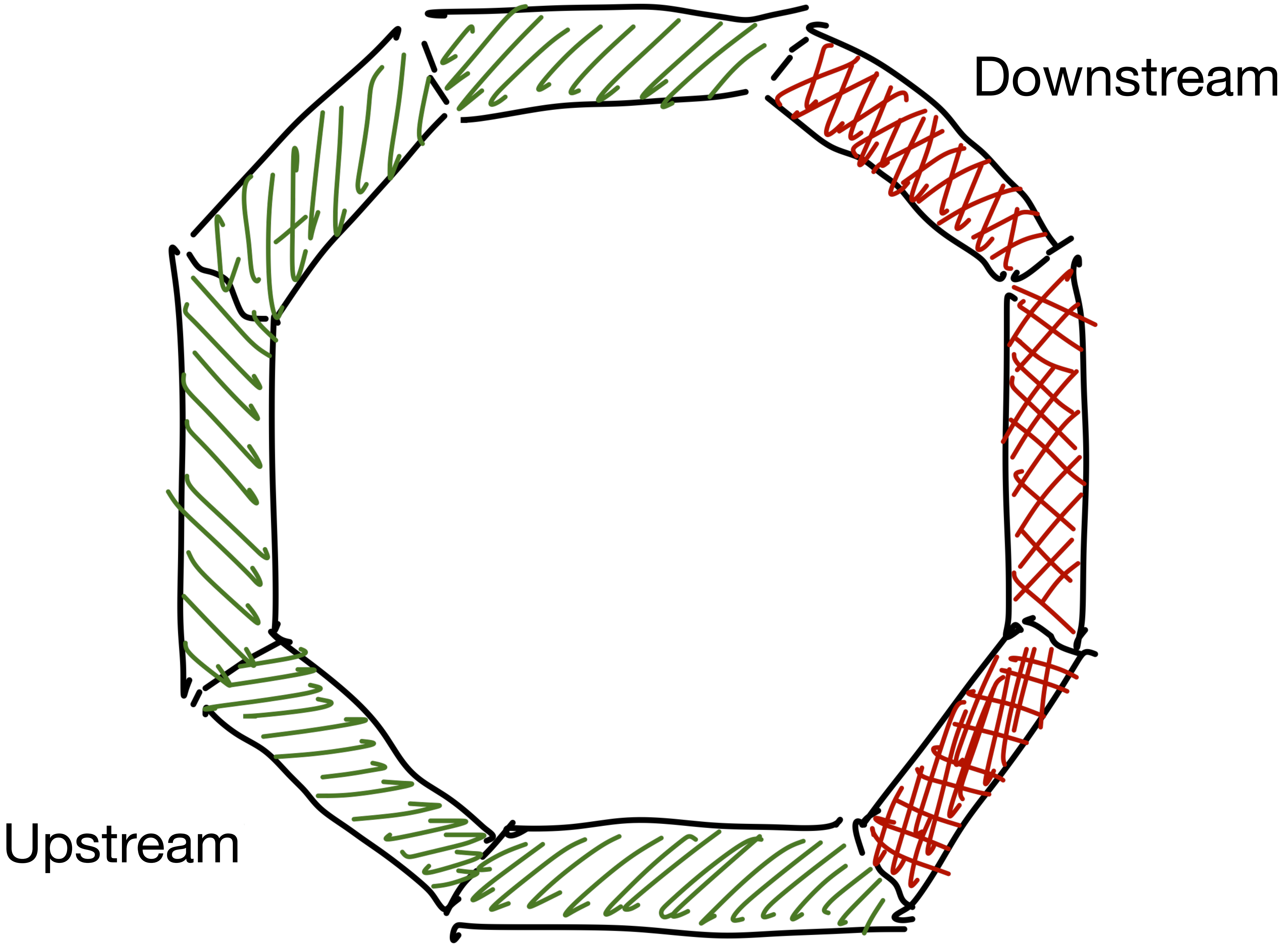
- Things tend to go forward - do not need the same granularity, and same depth / resolution everywhere
  - Obviously something that requires understanding and optimisation - in progress

Defining two regions:

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

Possibly variable longitudinal segmentation:

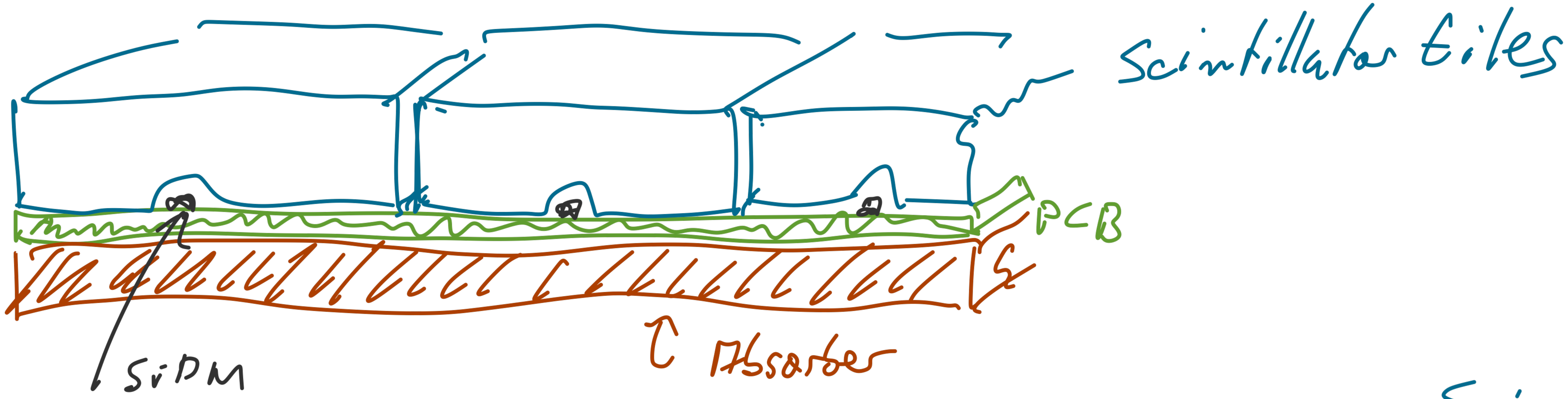
- thin layers in front to enable good energy resolution for low-energy photons
- thicker layers in the rear to ensure sufficient containment with a compact detector



Technology Choices & Options: Baseline

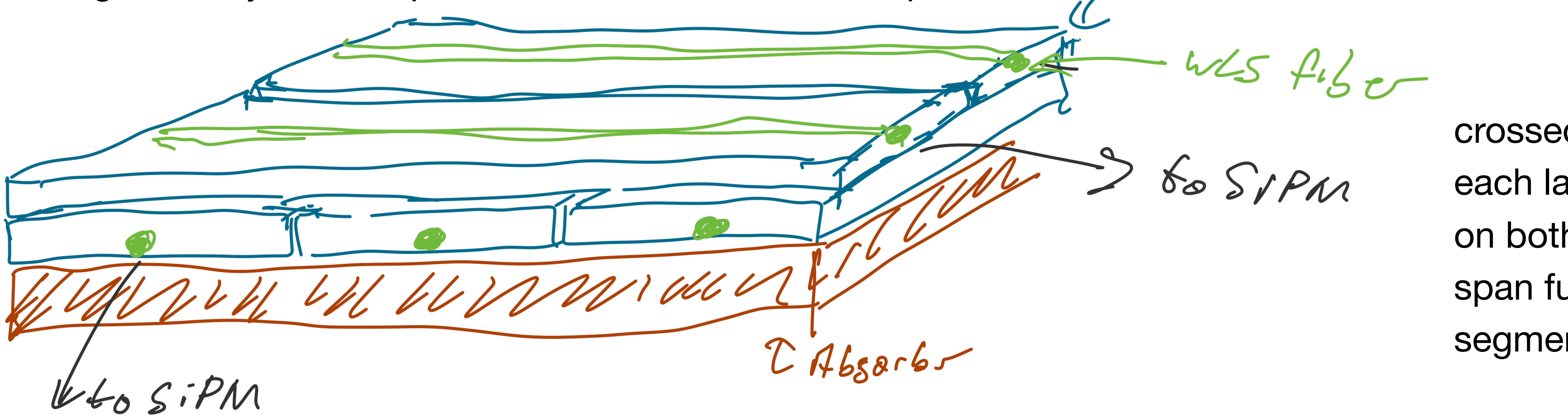
(Partially) based on CALICE AHCAL

- High granularity readout planes: scintillator tiles



one SiPM per tile

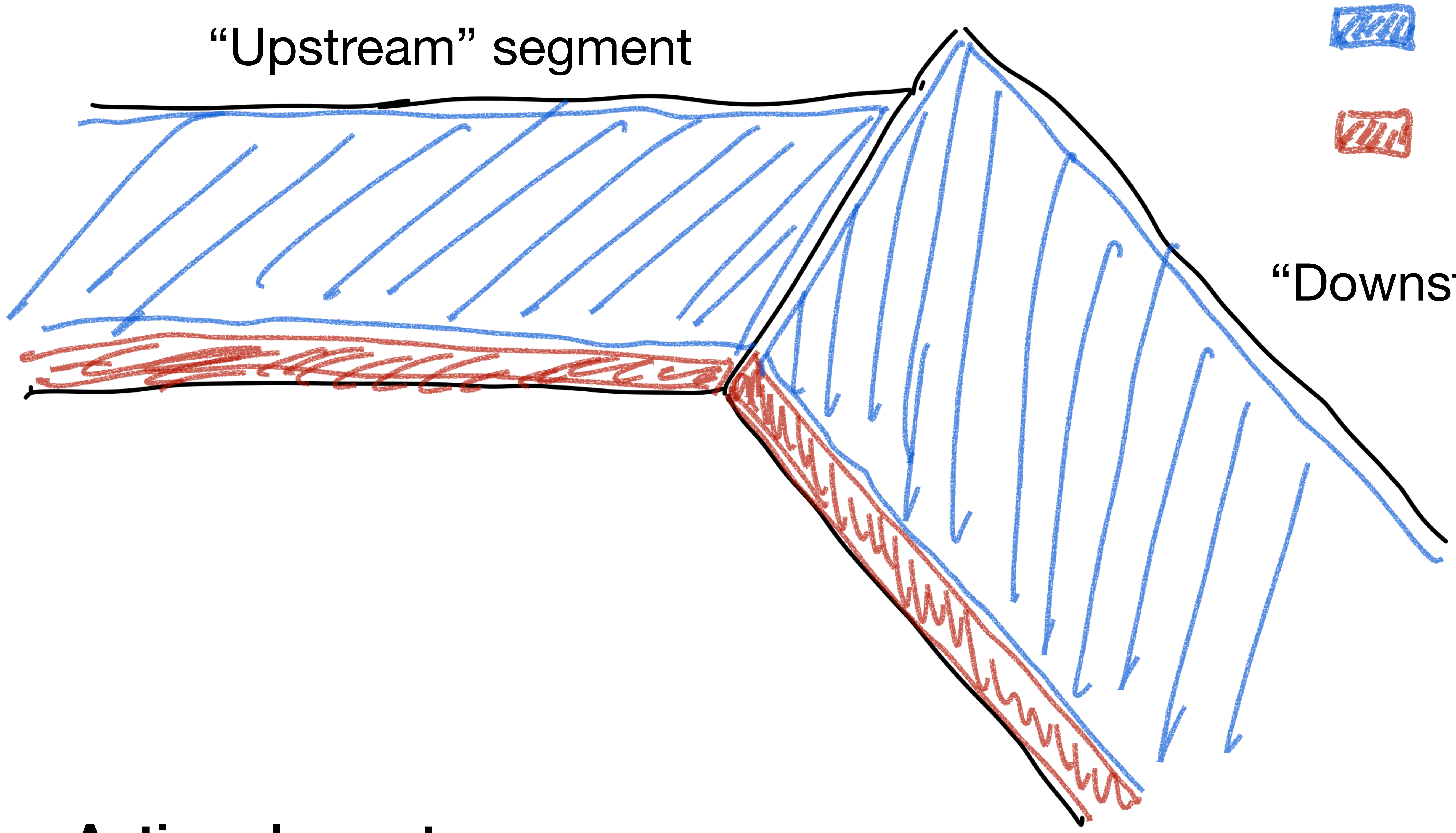
- Low granularity readout planes: crossed scintillator strips



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

The Current Detector Model

What is in the Document - not what will get built



low granularity layers: alternating orthogonal bars

high granularity layers: tiles

- Downstream layout [3 downstream octagon segments]:
  - 80 layers, first 8 high granularity
- Upstream layout [5 side and upstream segments, endcaps]:
  - 60 layers, first 6 high granularity

Active elements:

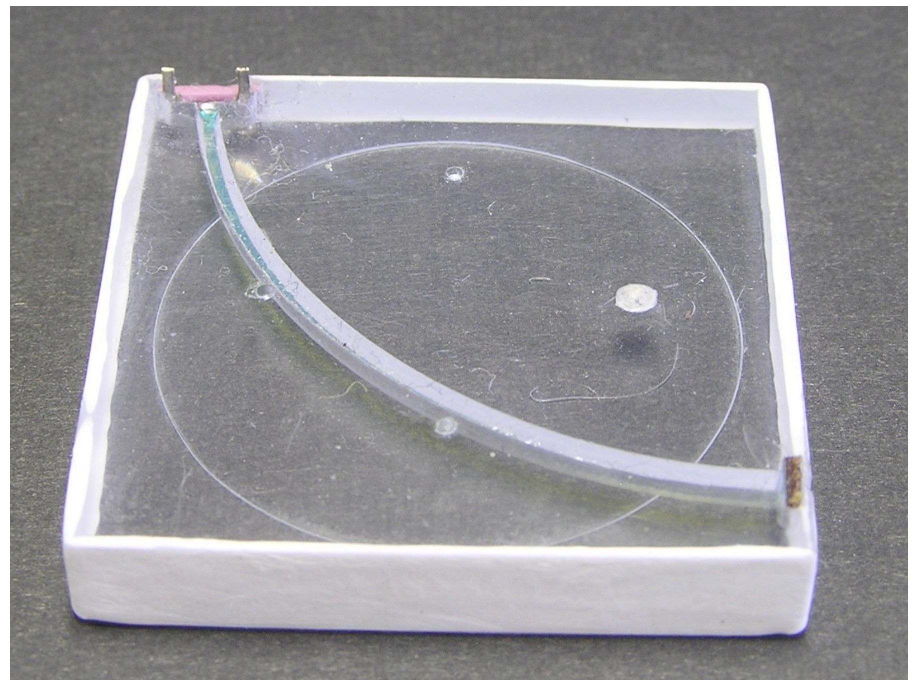
- *high granularity*: 25 x 25 mm^2 tiles, 5 mm thick
- *low granularity*: 40 mm wide, 5 mm thick bars over full module length, crossed in alternating layers

SiPM-on-Tile Technology

A closer look

- From the first large-scale application of SiPMs to the “***SiPM-on-tile***” technology

2008 - 2016



Physics Prototype

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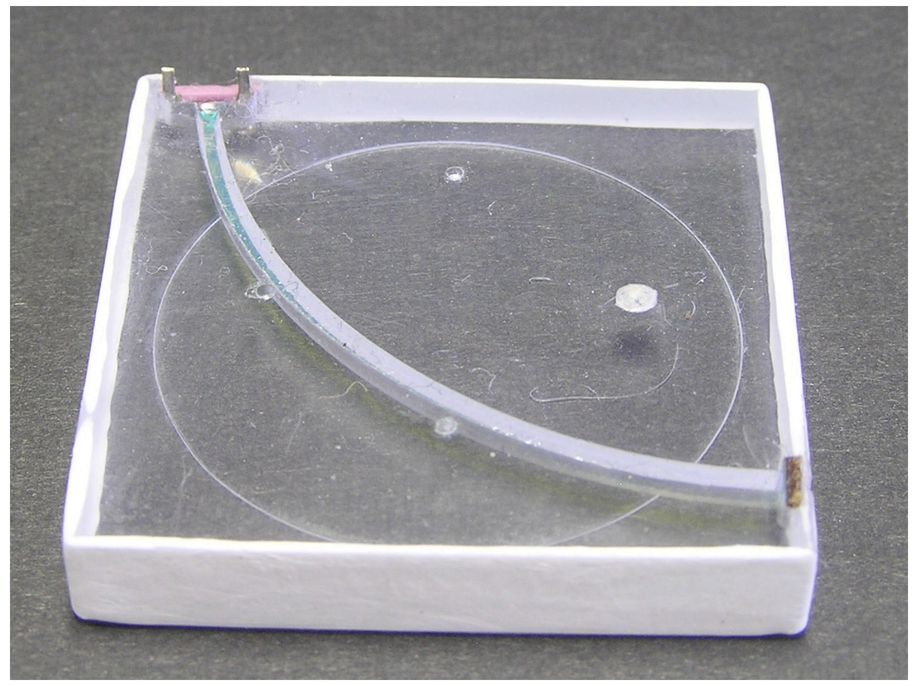

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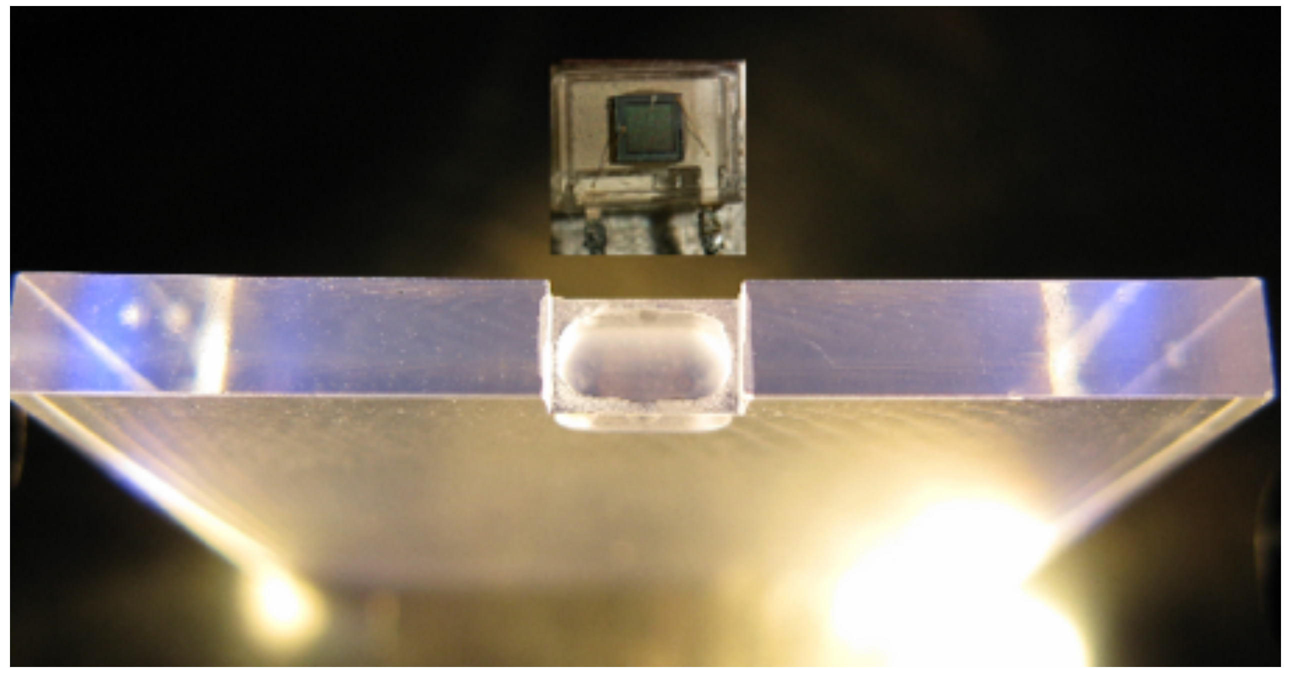

Direct coupling of tiles and photon sensors

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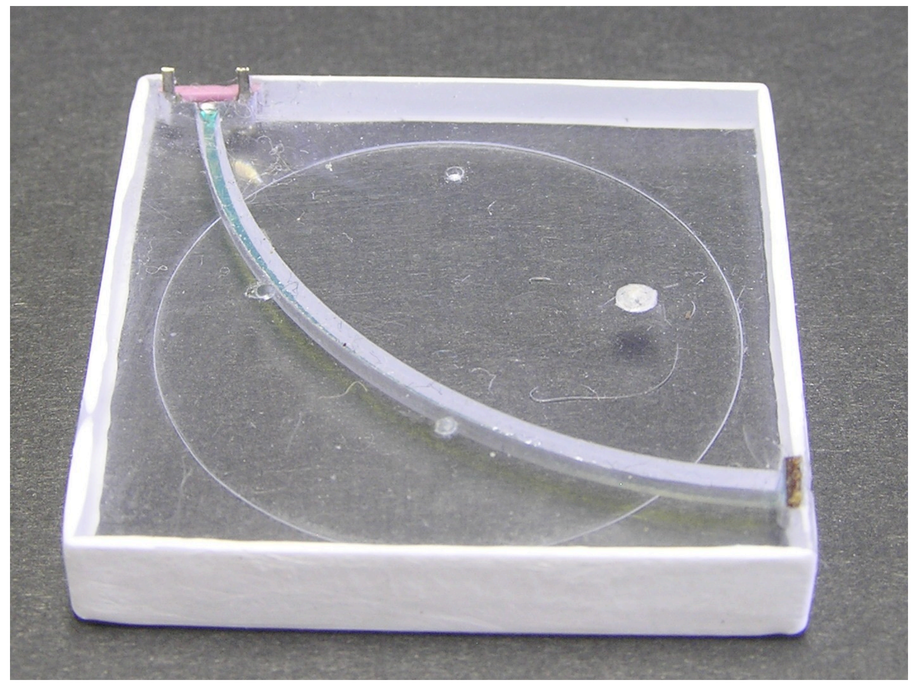

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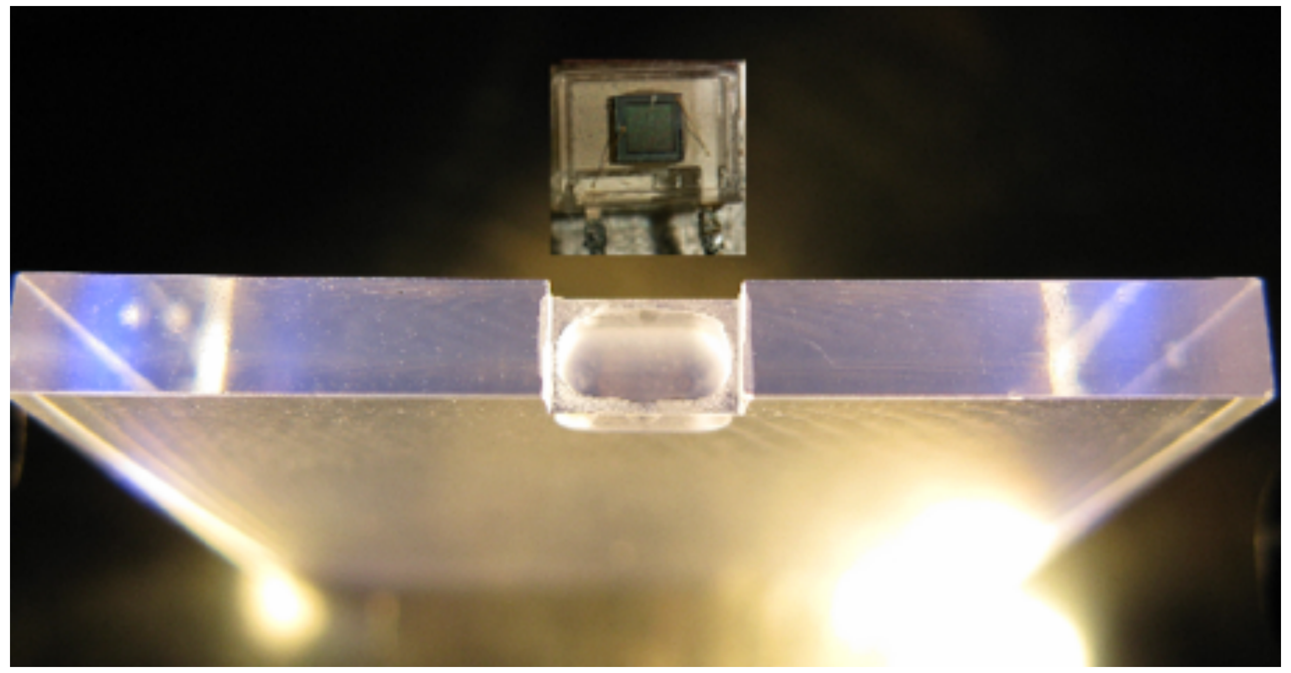

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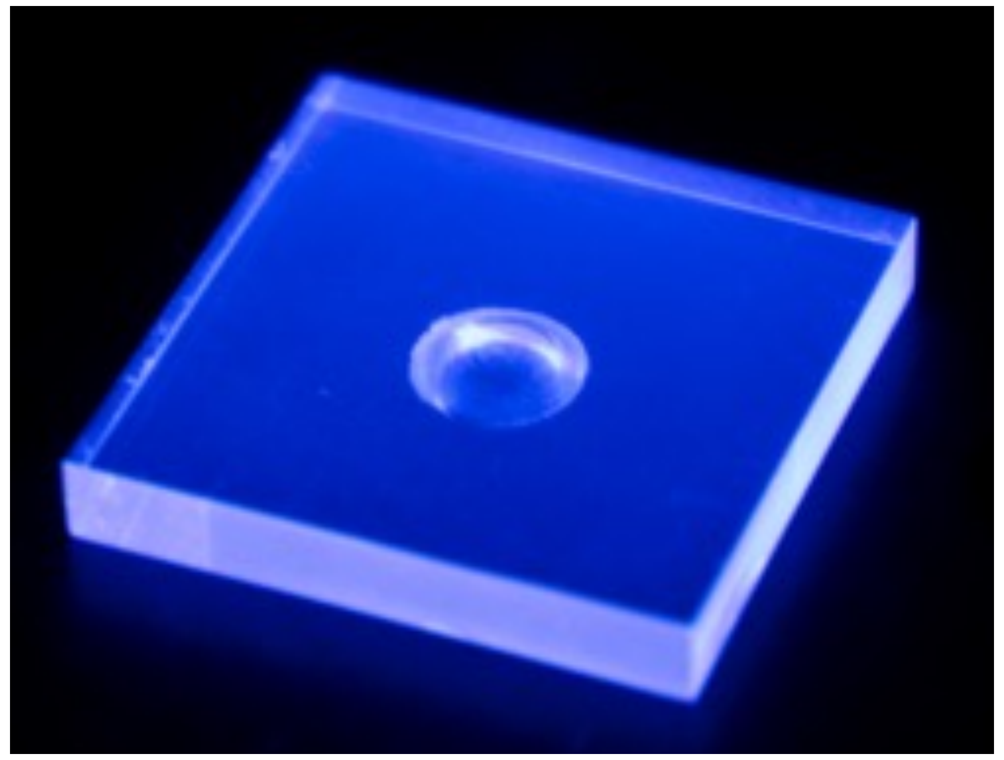

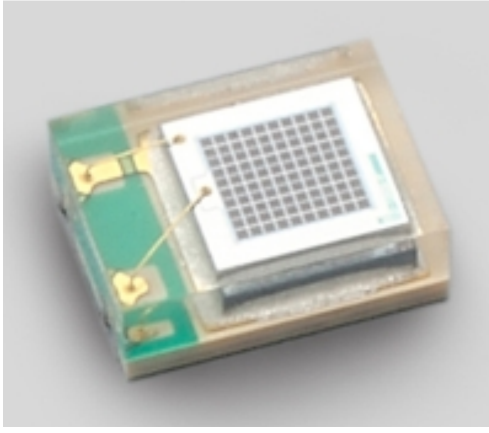

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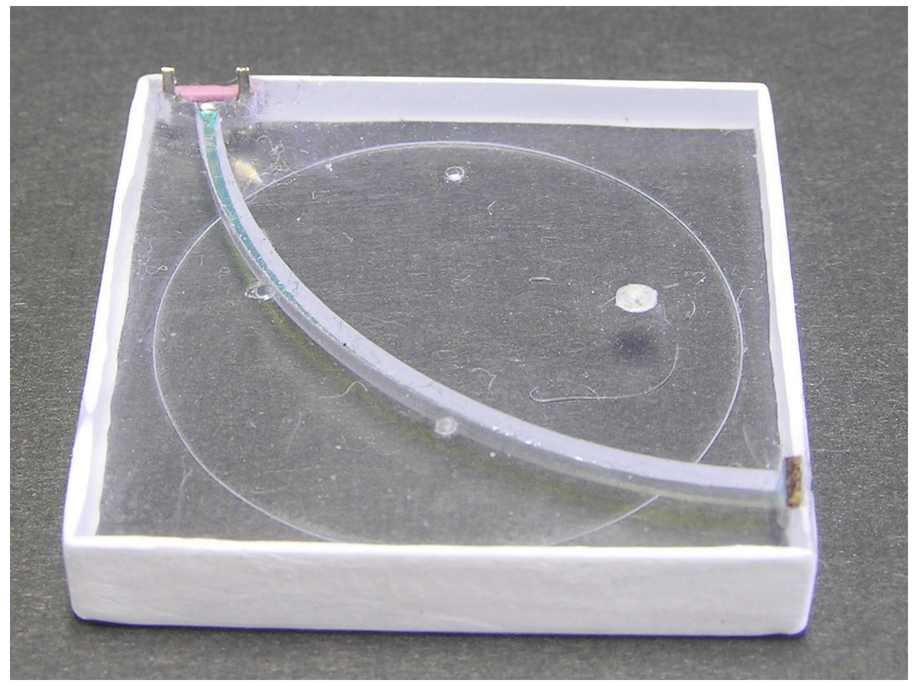

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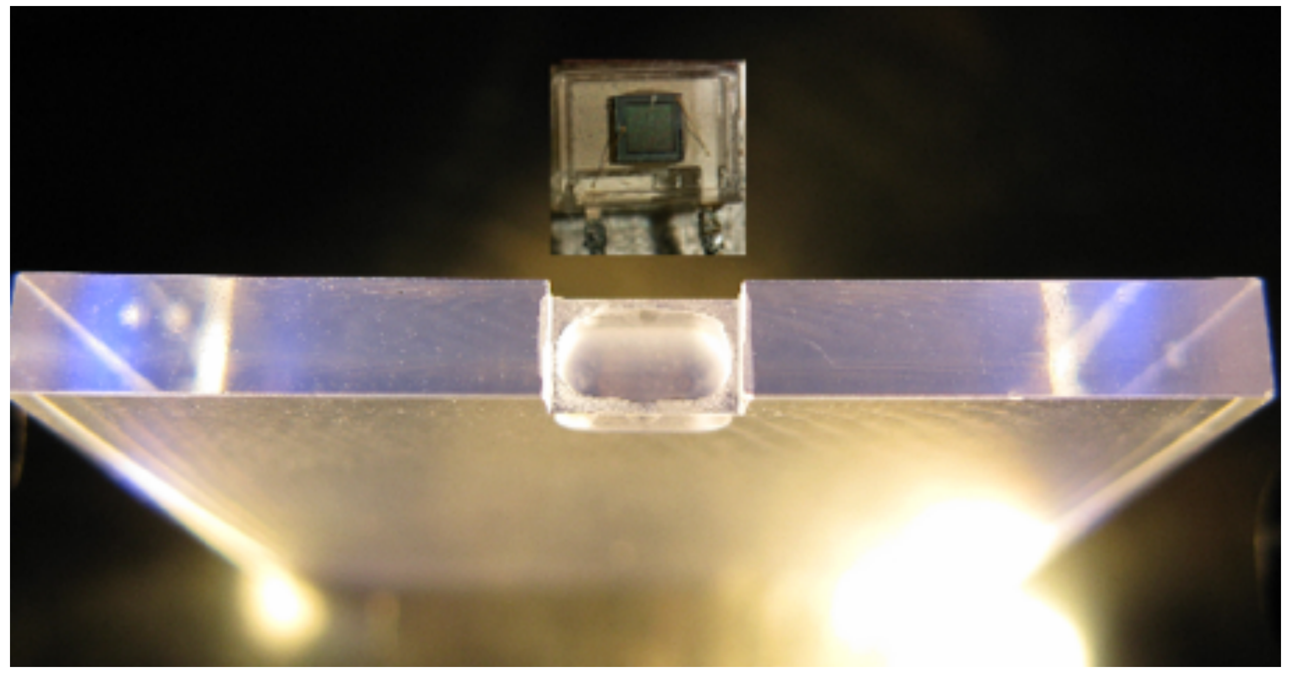

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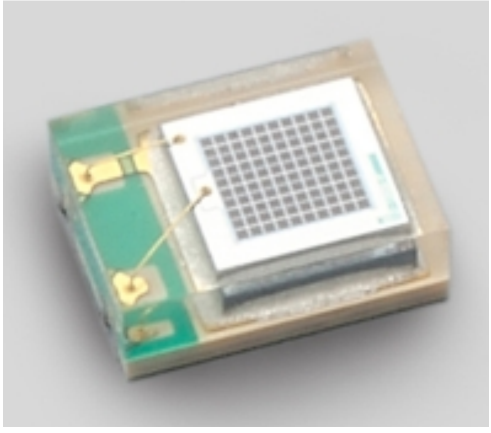

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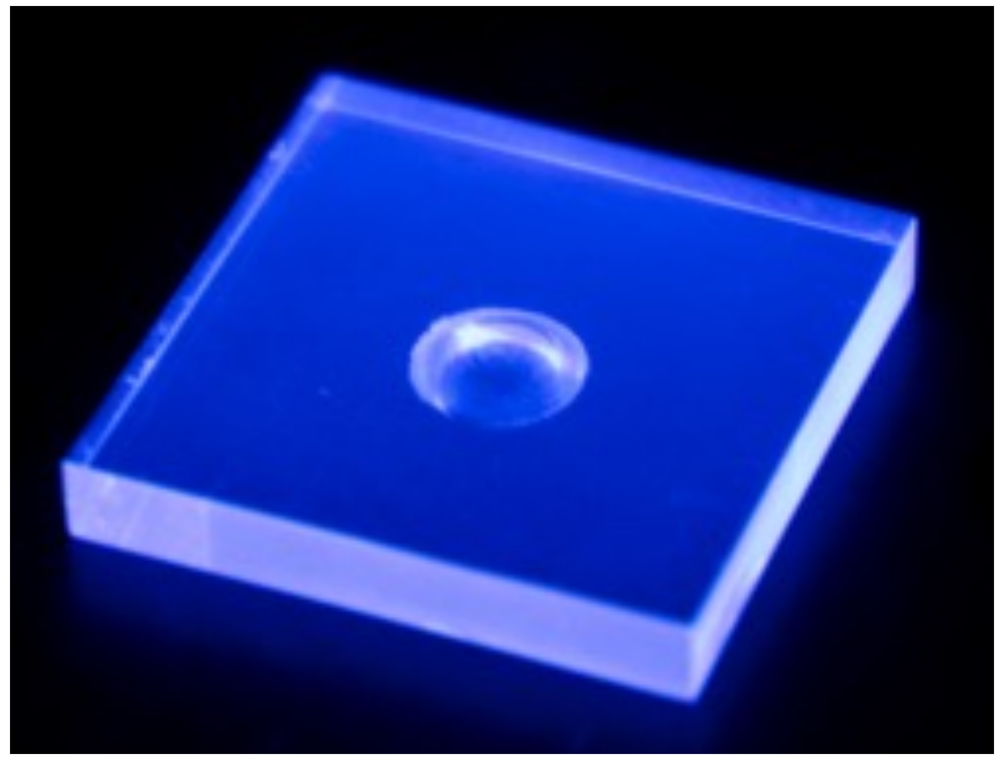
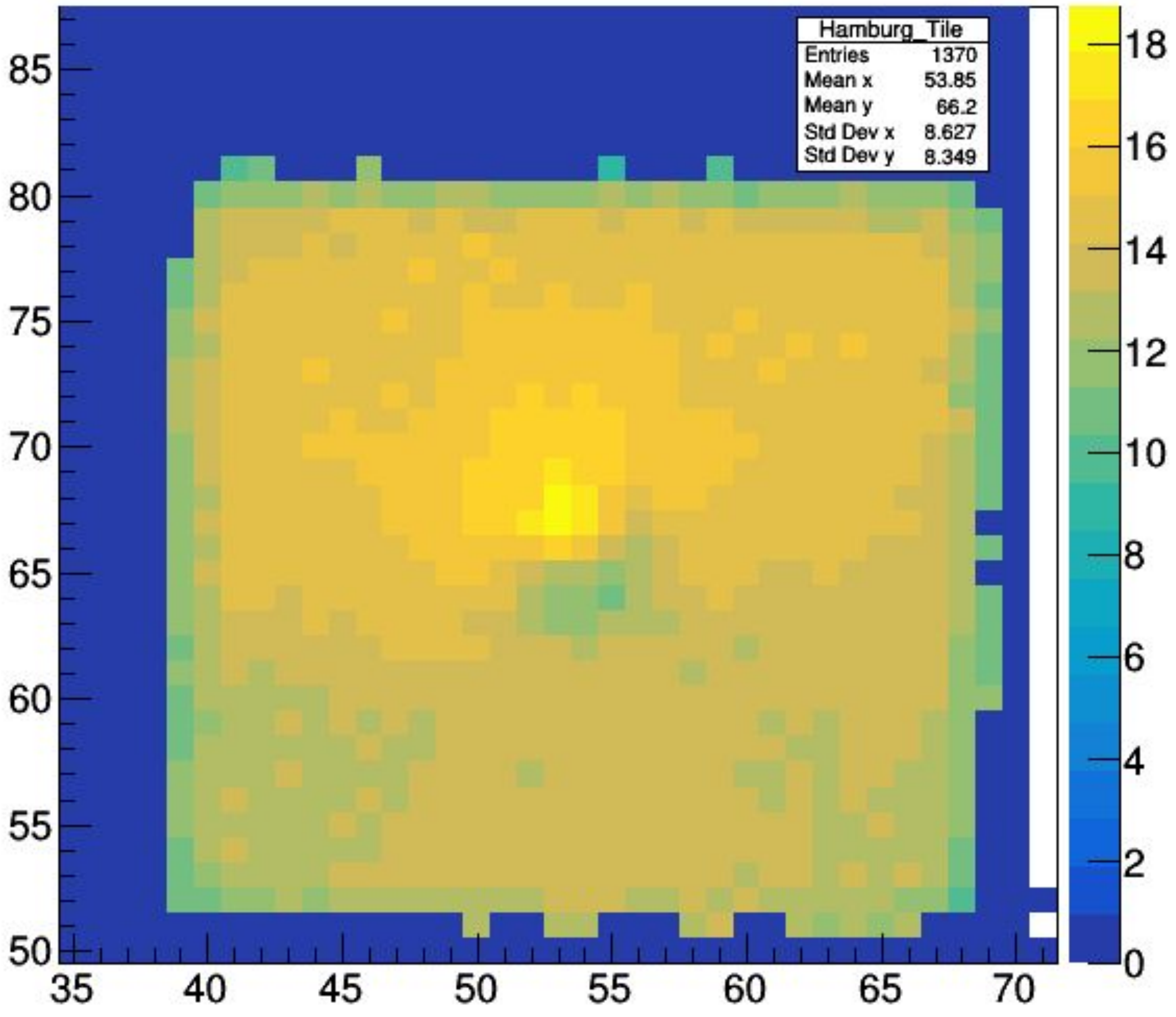


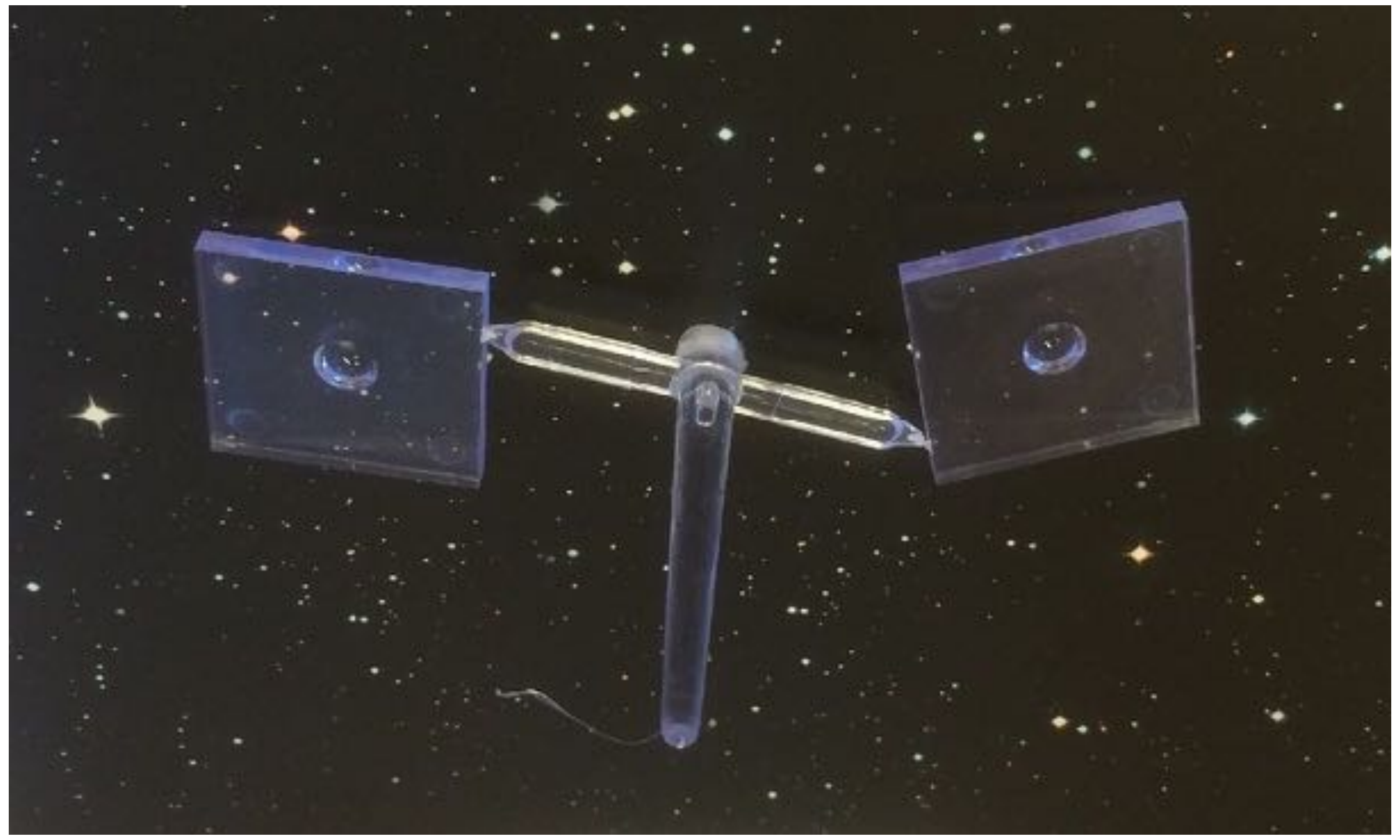
verification of tile performance in the lab



SiPM-on-Tile Technology

A closer look

- Mass production for a new 0.5 m³, 22k channel prototype
  - 24k tiles produced & wrapped



injection molding of PS based scintillator tiles

09/2017

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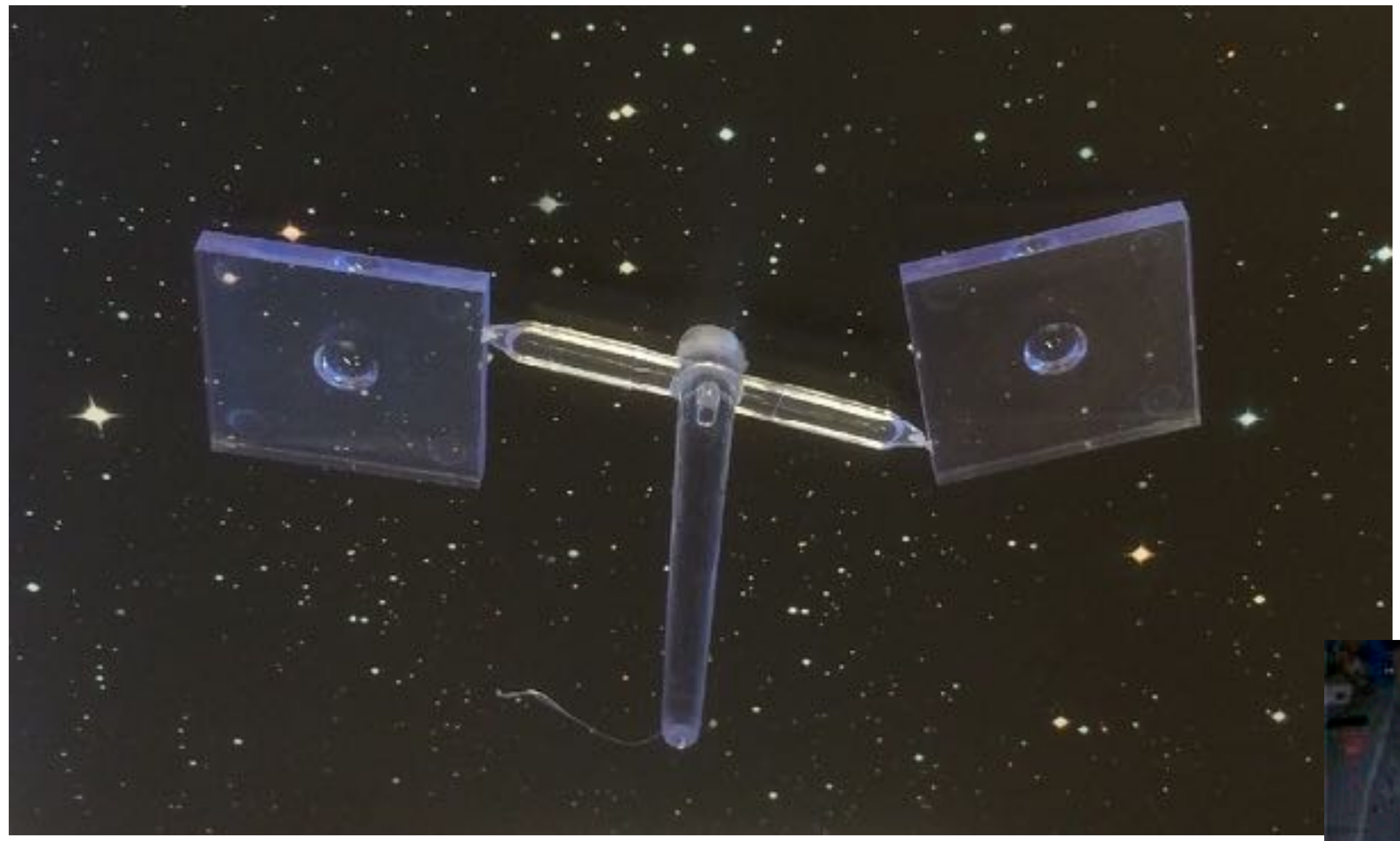

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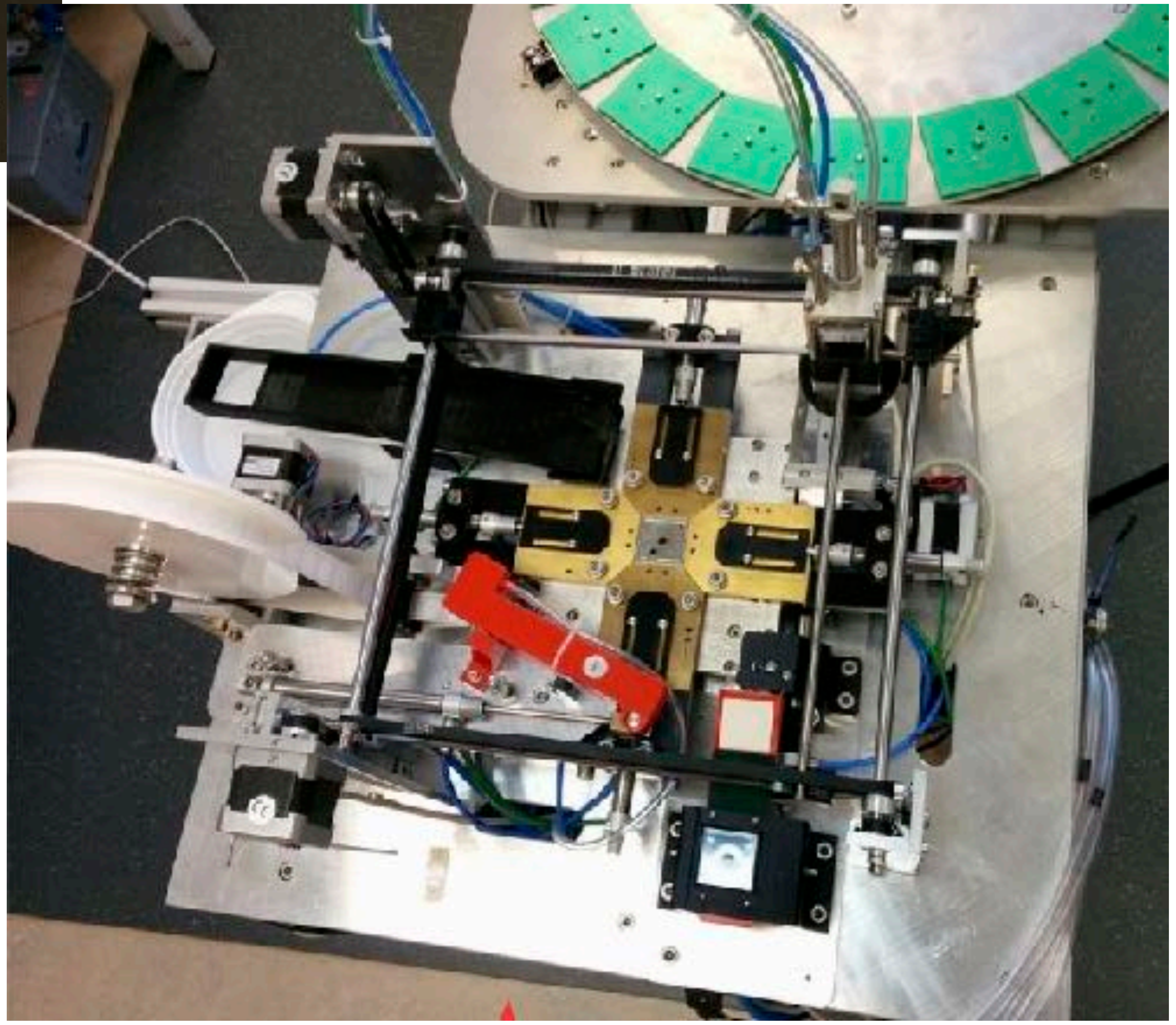

10/2017 - 01/2018

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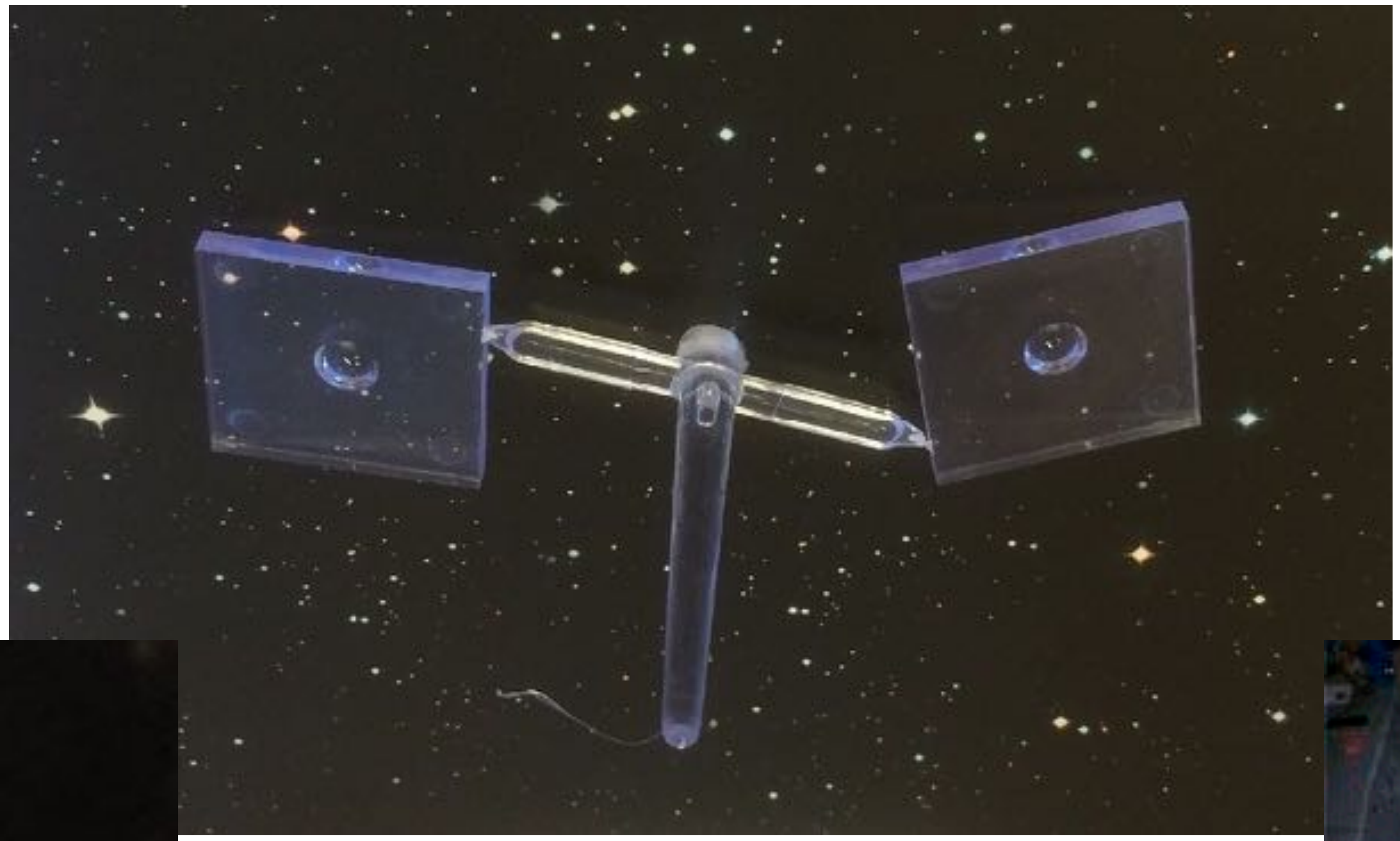

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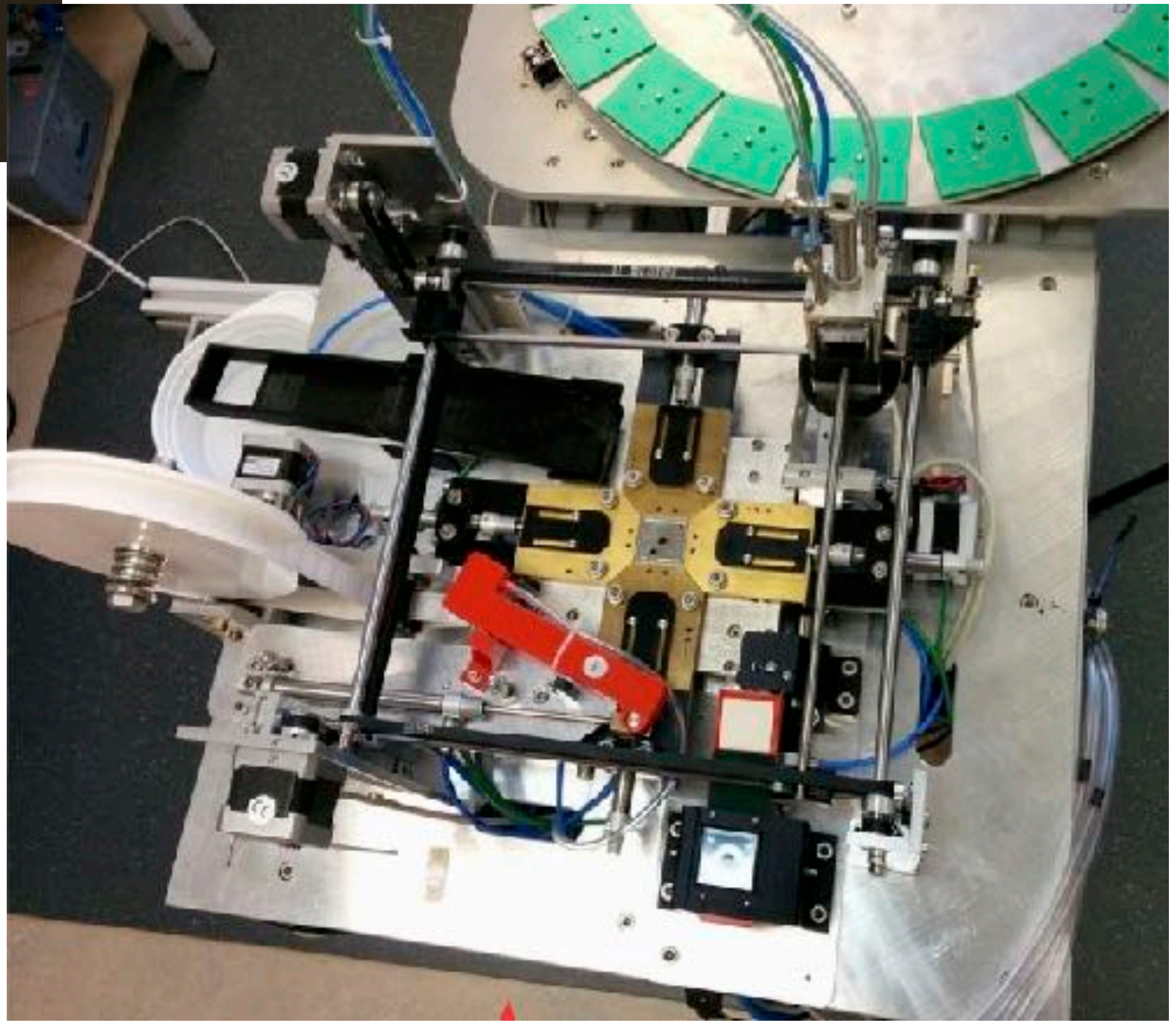


semi-automatic wrapping of scintillator tiles

10/2017 - 01/2018

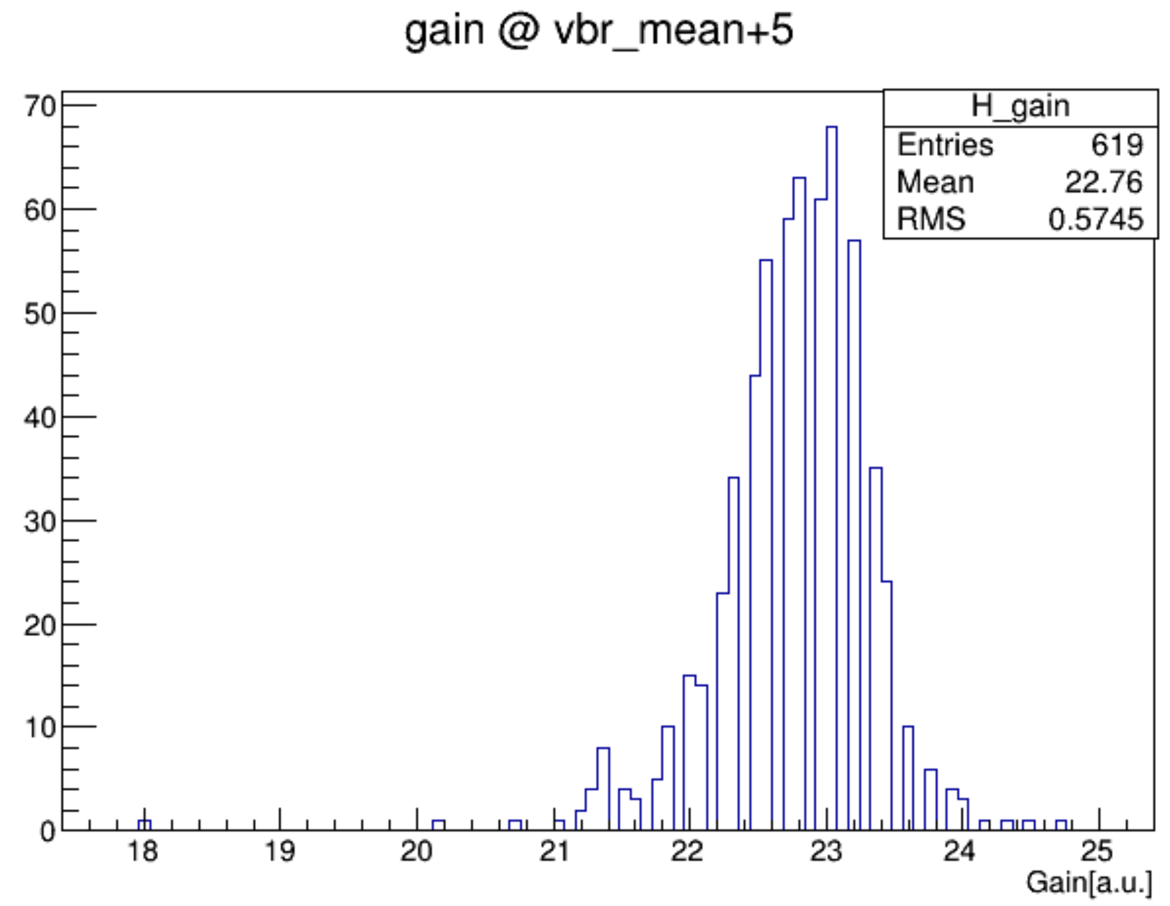
automatic placement of tiles on electronics board (HBU), fully assembled with SiPMs and ASICs

11/2017 - 02/2018

SiPM-on-Tile Technology

A closer look

- A multi-step QA procedure



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SiPM-on-Tile Technology

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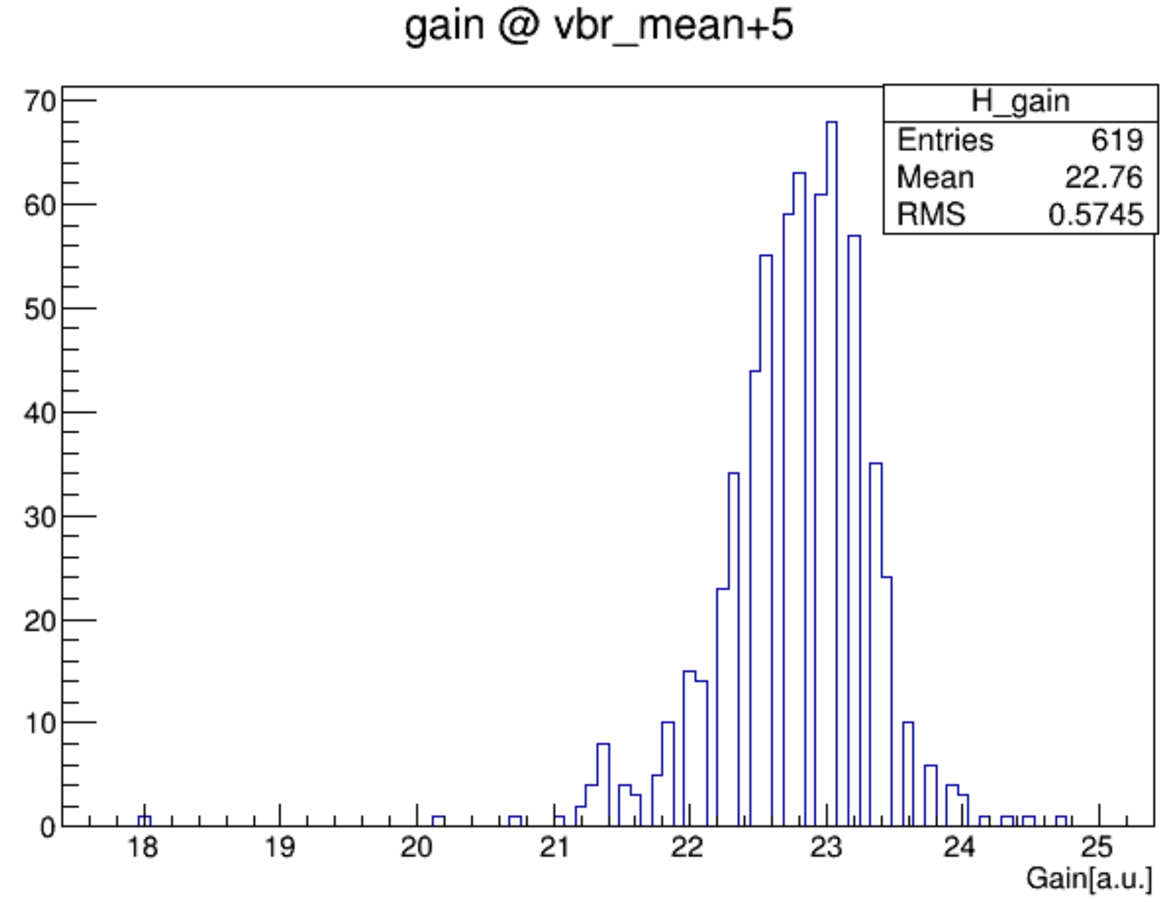

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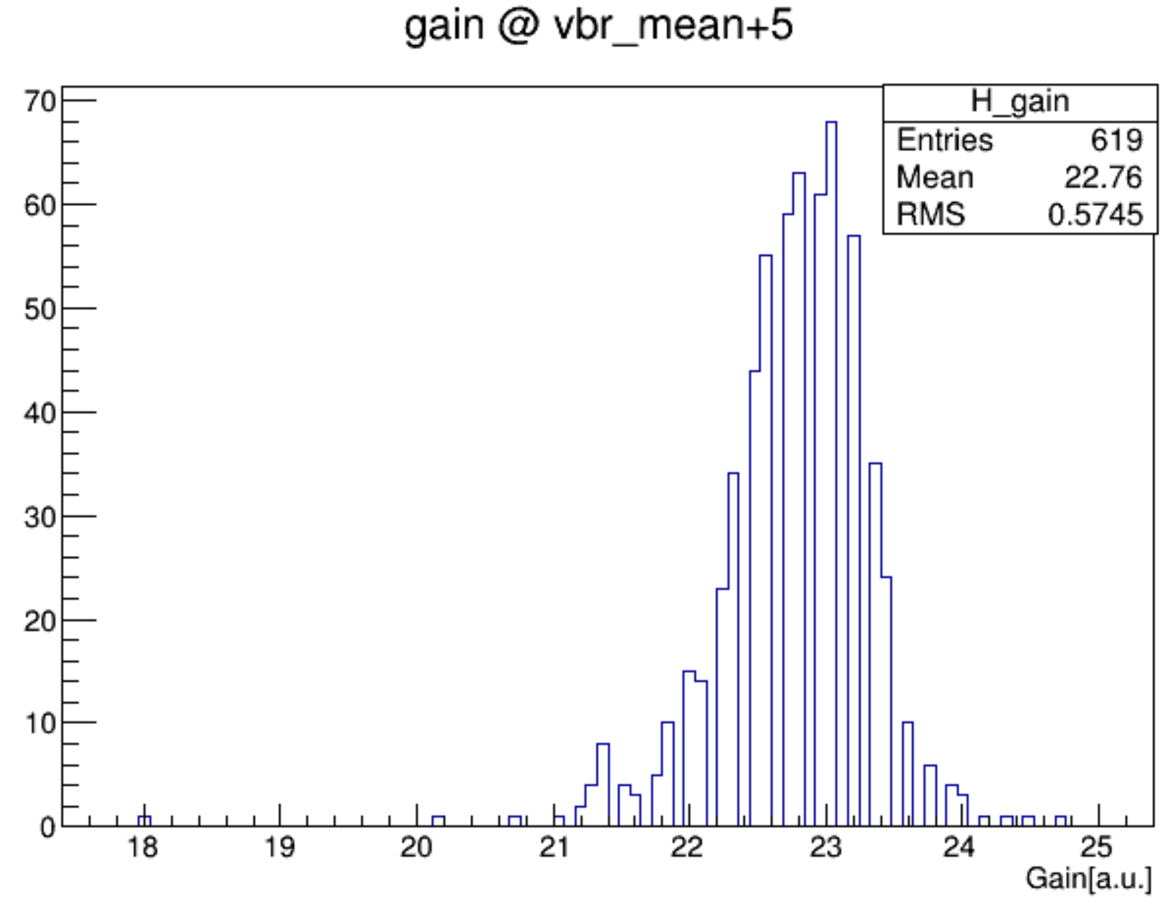

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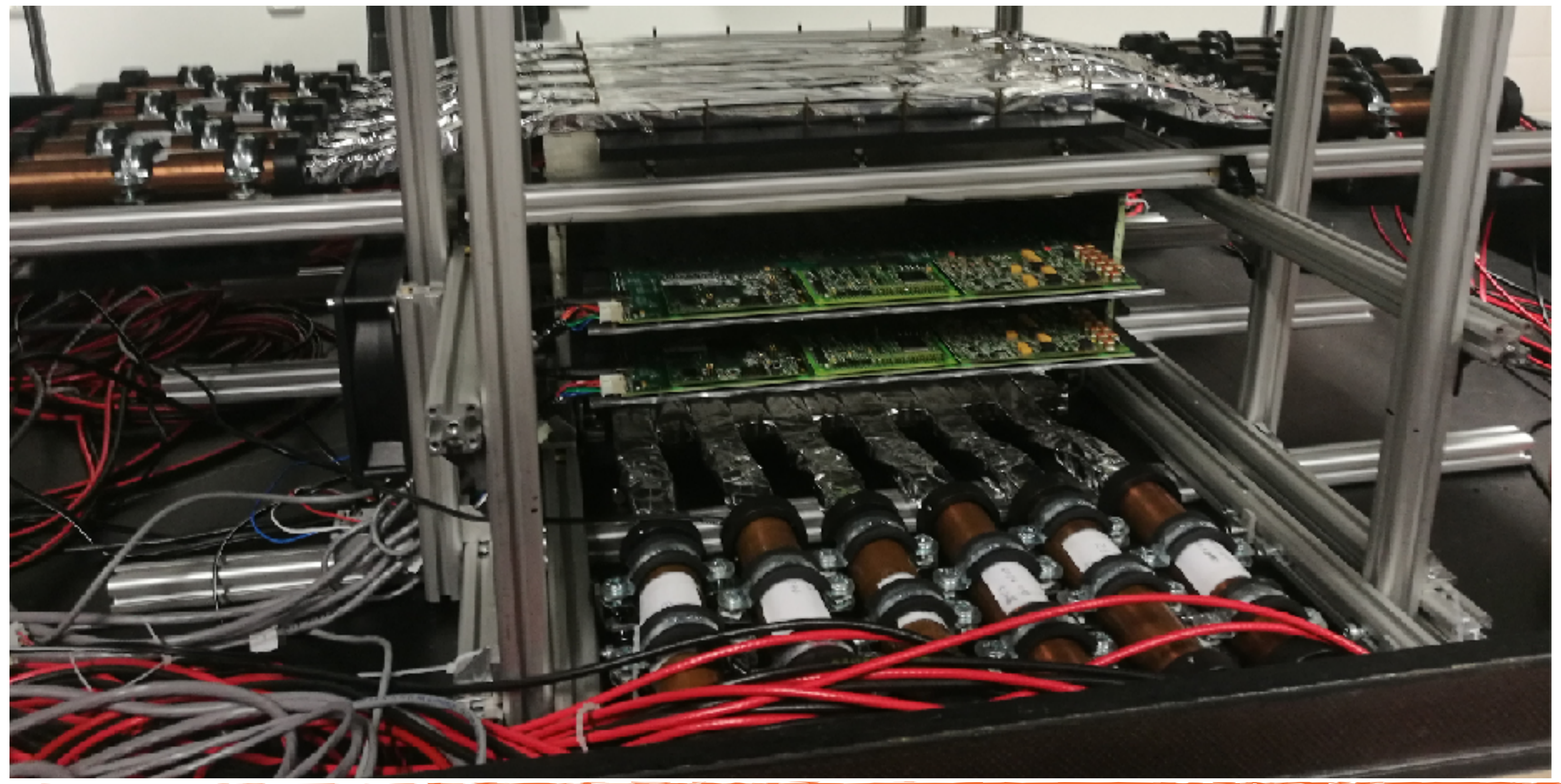


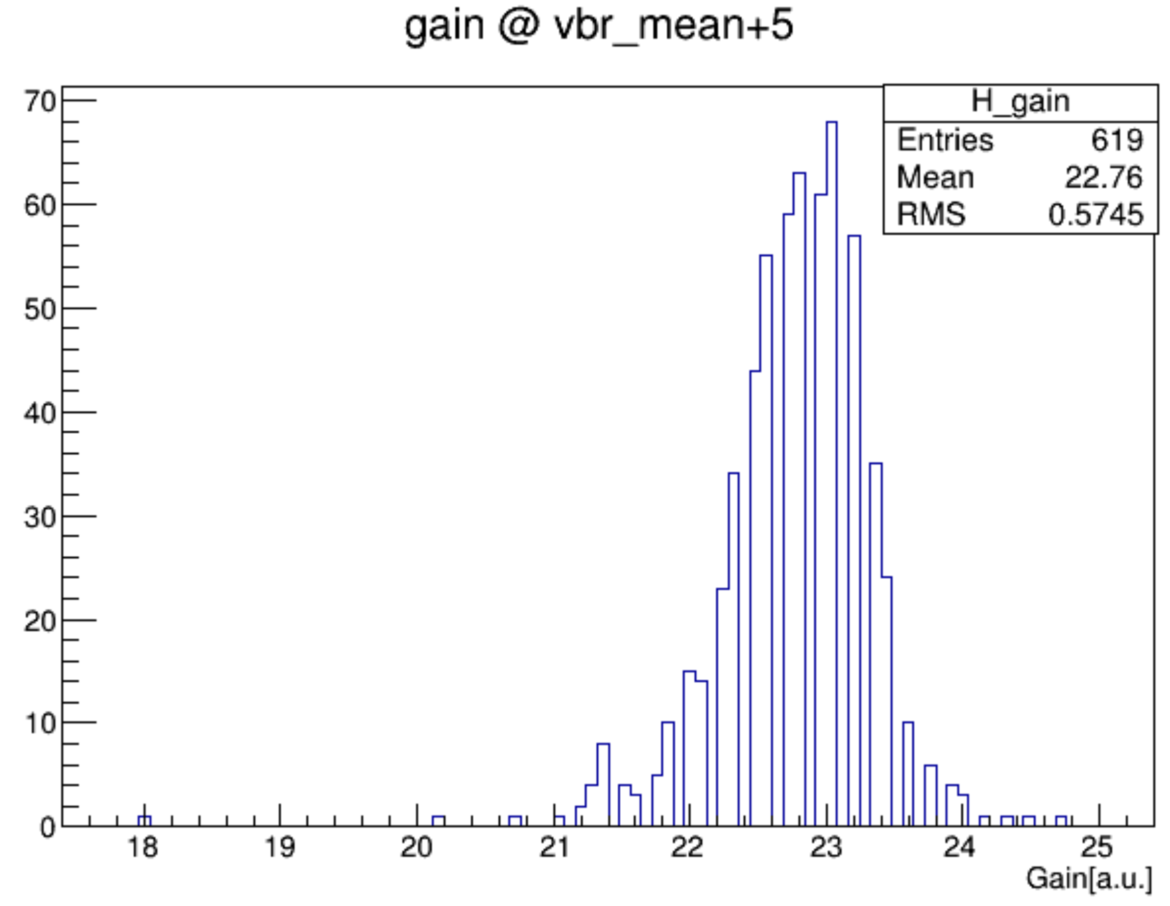
test and calibration of all channels with cosmics

SiPM-on-Tile Technology

A closer look

- A multi-step QA procedure

integration of layers & interfaces, test in beam at DESY



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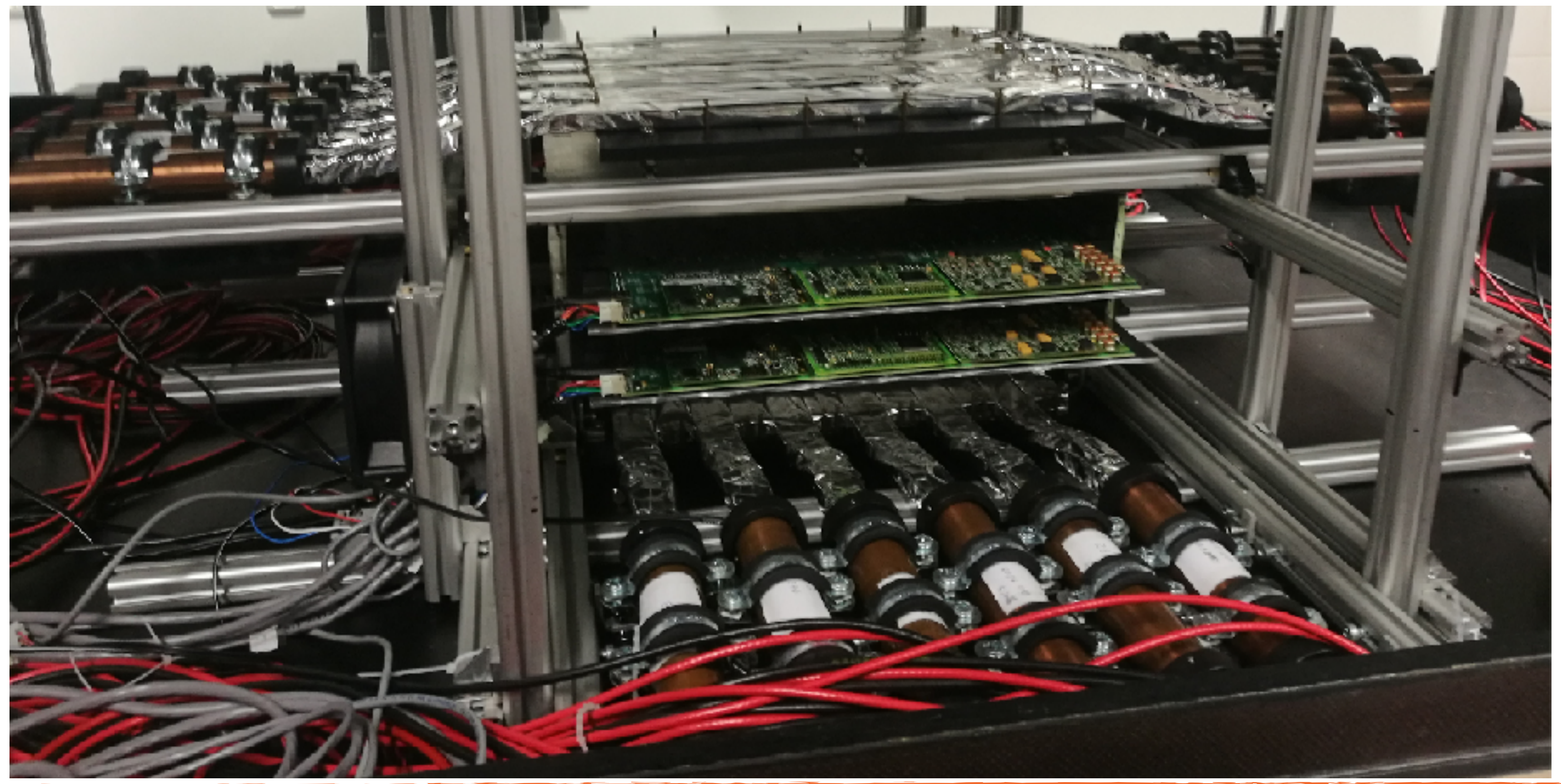

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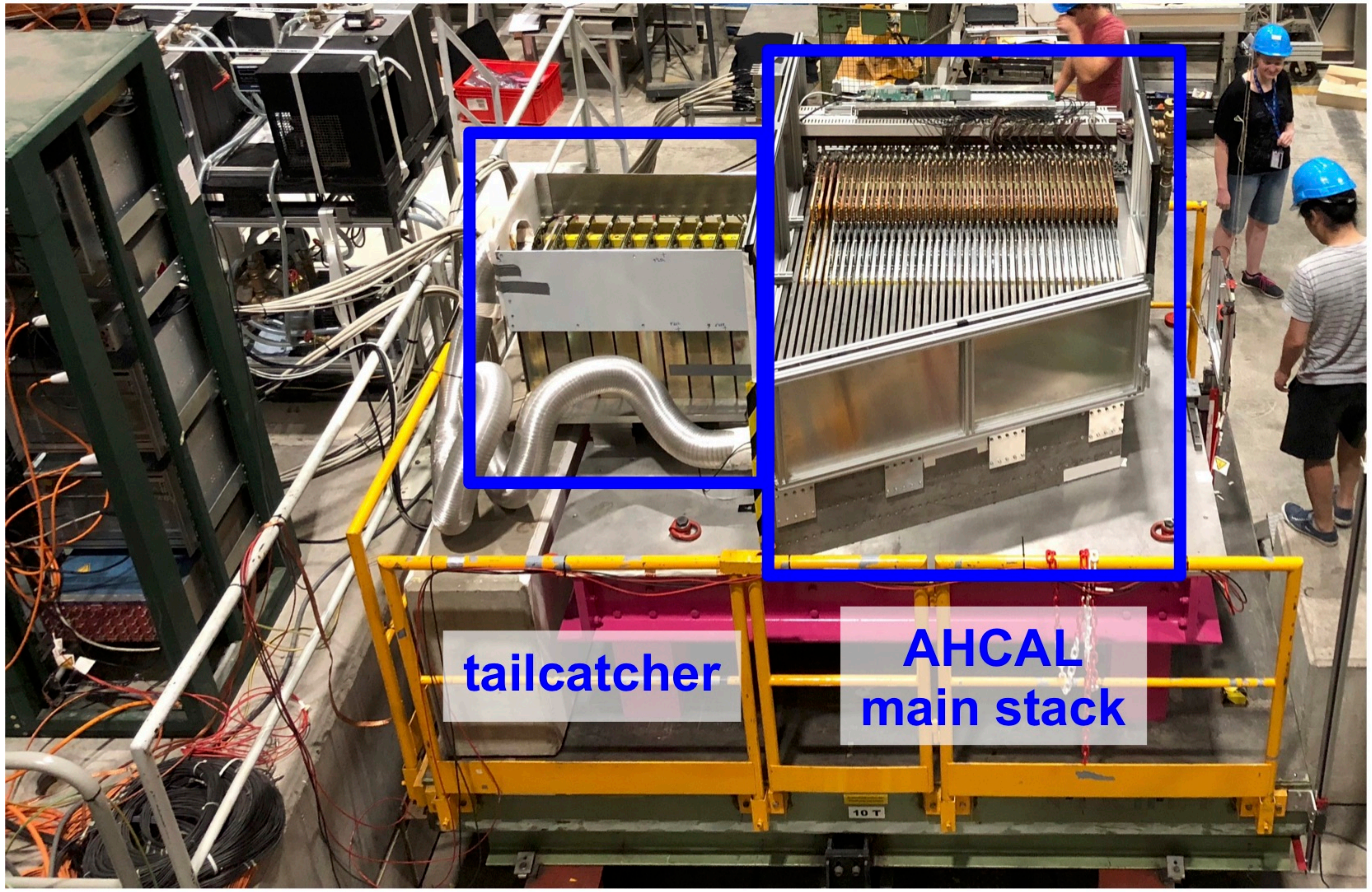
SiPM-on-Tile Technology

A closer look

- In May and June 2018: Test beam at CERN SPS - the smoothest CALICE test beams ever.



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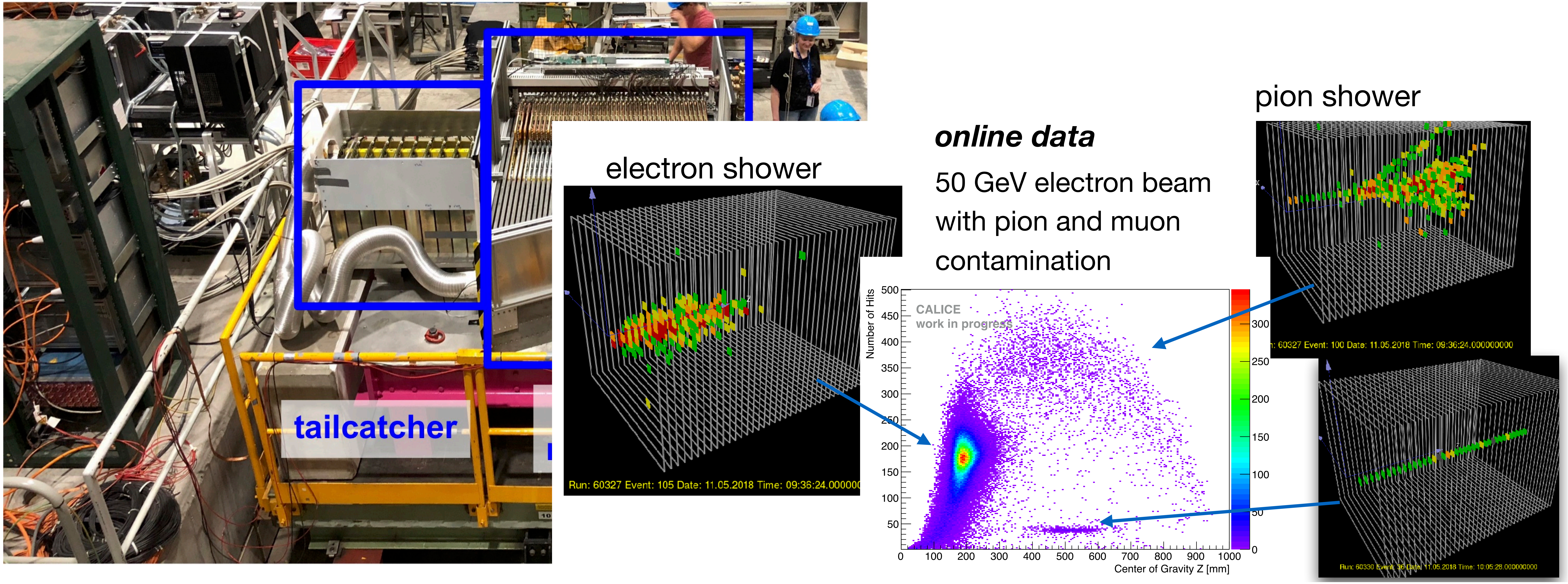
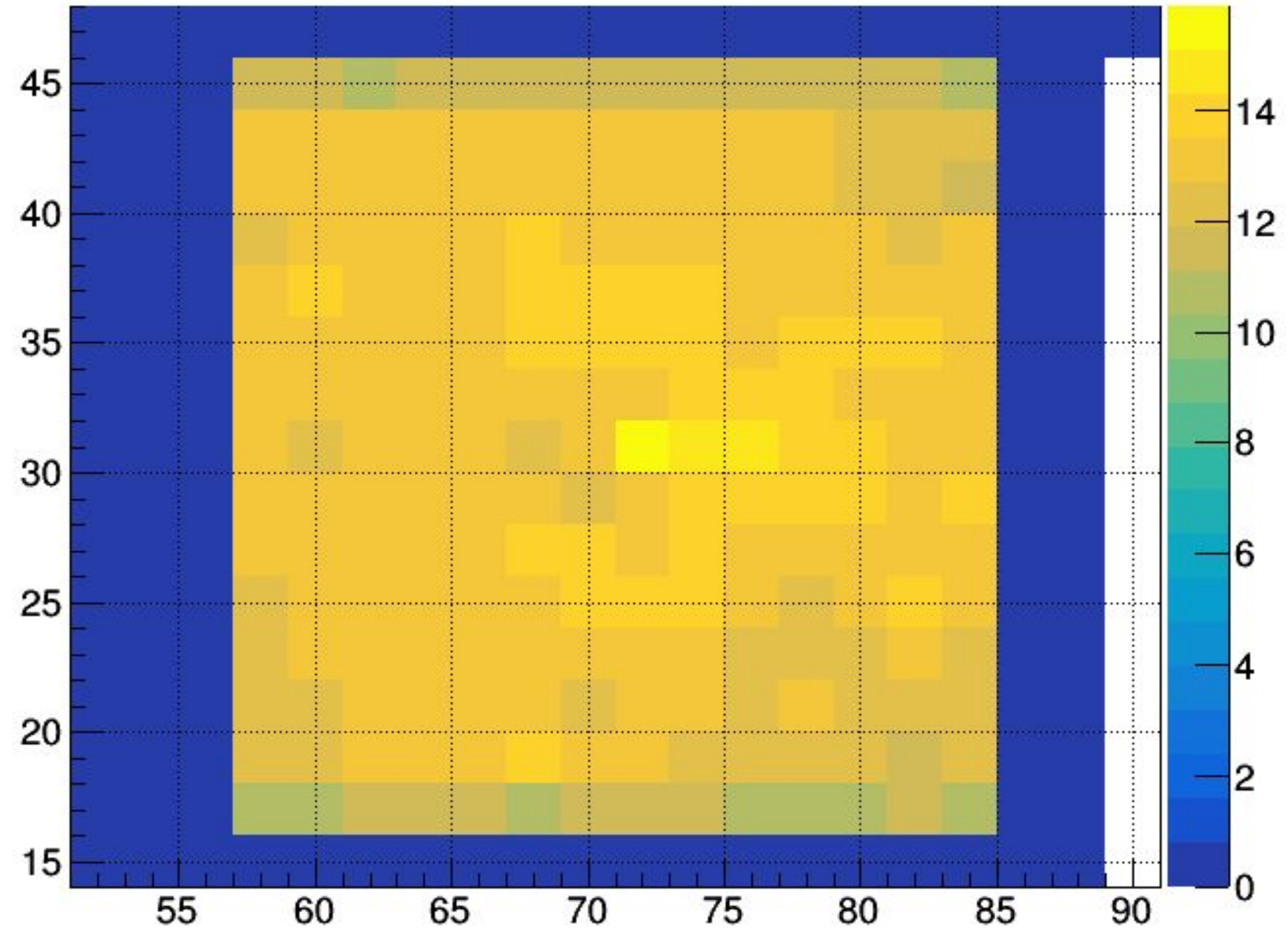


- Analysis ongoing - first results soon

SiPM-on-Tile for the ND ECAL

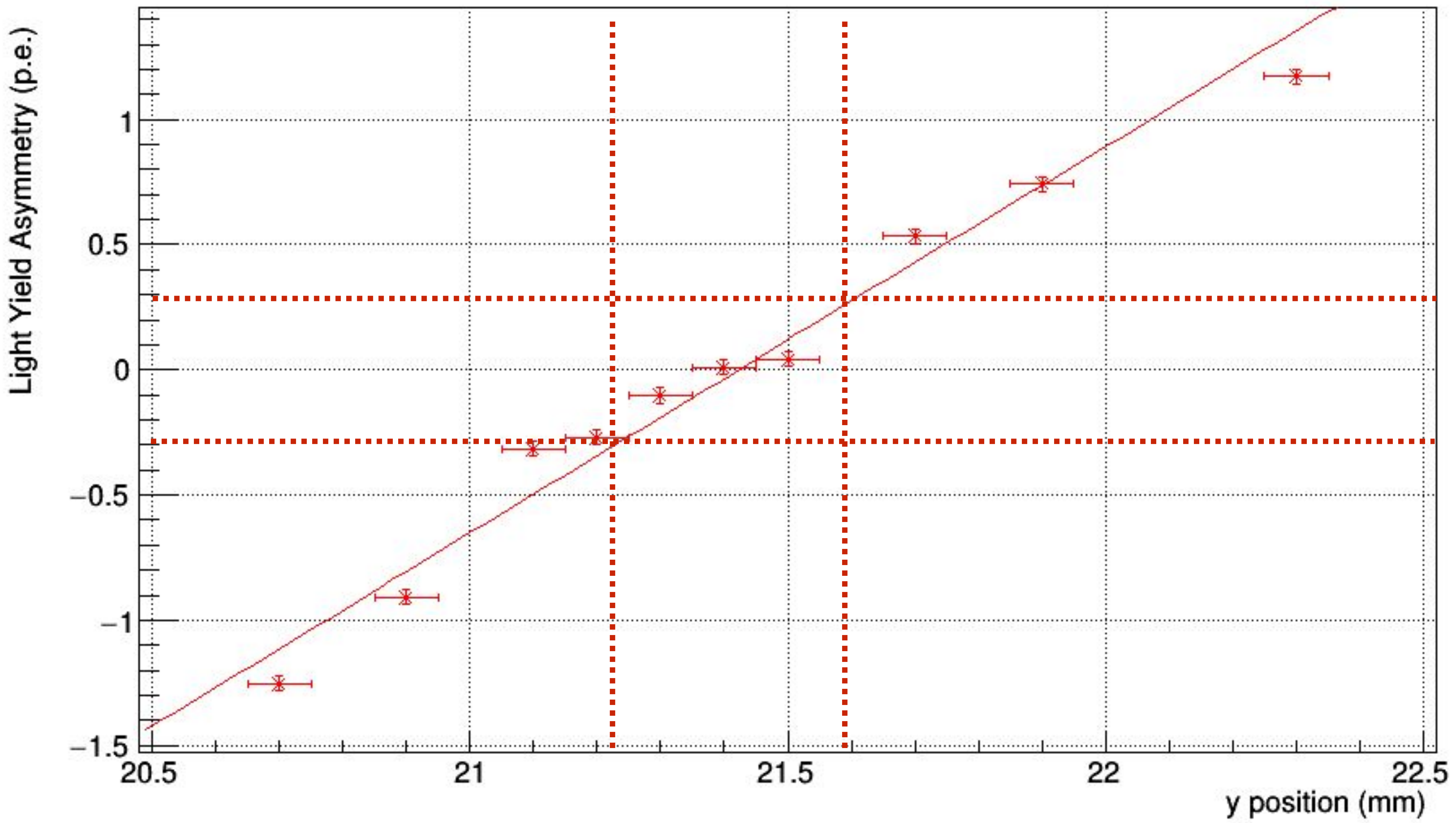
Understanding Impact of Tile imperfections

- Response of scintillator tiles not perfectly uniform



Typical variations 5 - 10% over tile surface, large fraction within a few % of mean

- Assembly tolerances leading to misalignment between SiPM and tile can lead to increased non-uniformity



Misalignment generates a “dipole” in the response: global asymmetry in direction of misalignment

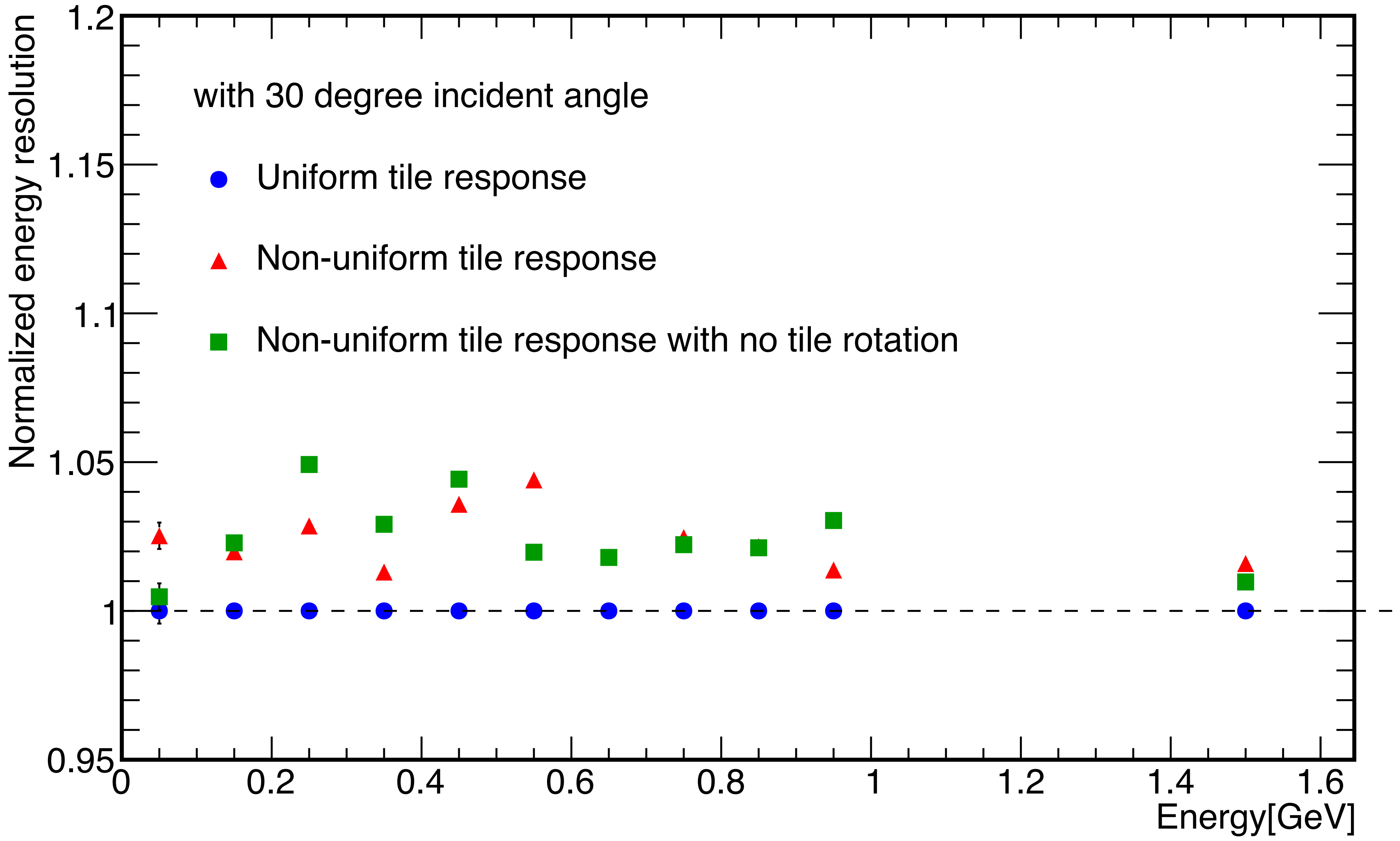
2% asymmetry for 175 μm offset

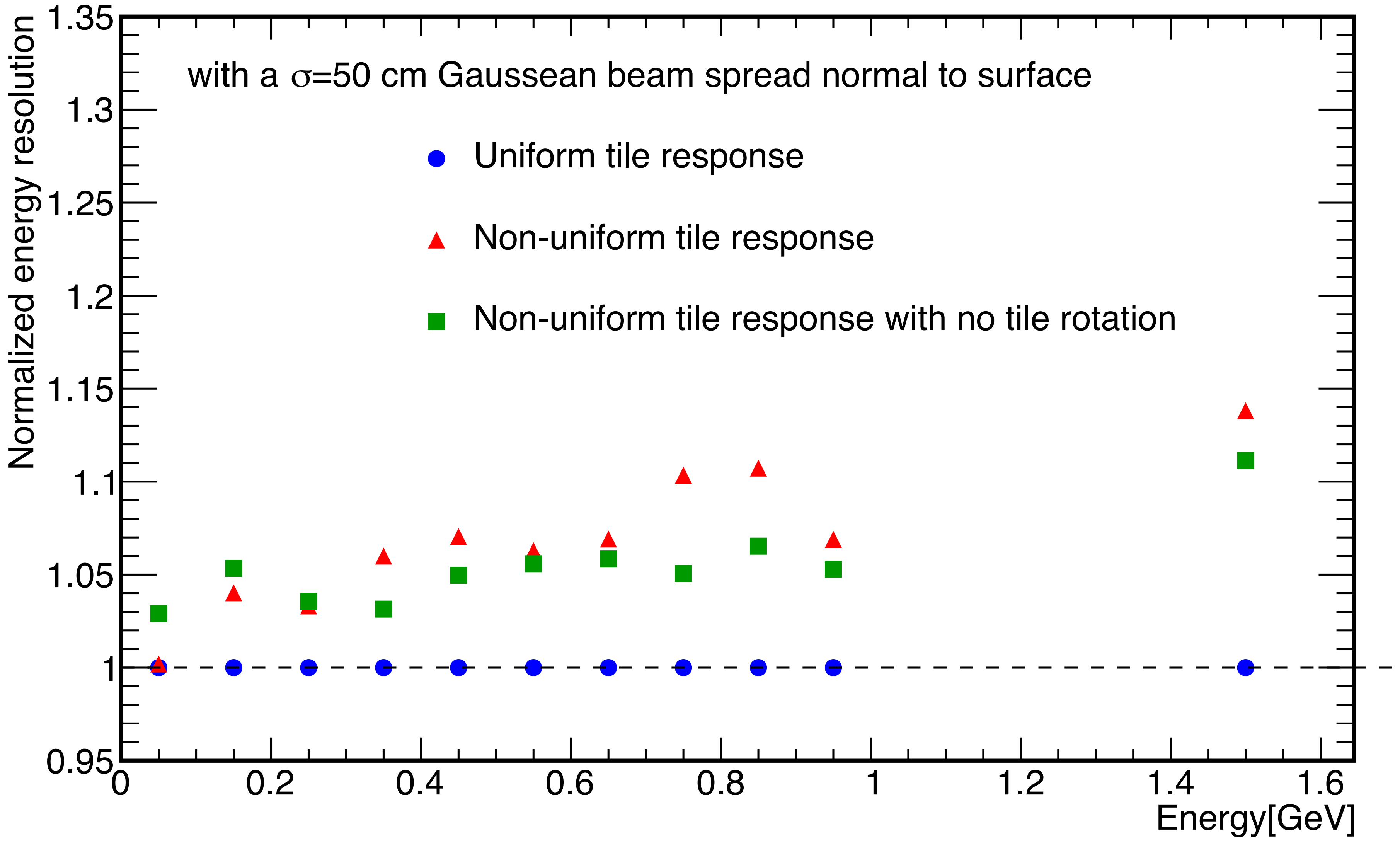
Expect 100 μm easily achievable

SiPM-on-Tile for the ND ECAL

Understanding Impact of Tile imperfections

- Simulations of an "infinitely thick" tile-only ECAL with realistic non-uniformities implemented, including effects of ~ 100 µm SiPM / tile misalignment
  - at present all layers the same: expected to be more damaging than random alignment
  - random orientation within each layer also studied





typically ~5% degradation, worse for near-normal incidence at high energy

200 µm dead zone around each tile adds a comparable degradation

Bottom line: By no means a show-stopper - SiPM-on-tile useable also for high-resolution ECAL

➩ Next step: Understand impact of non-uniform material distribution induced by ASICs inside layers…

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
  - Fibers are a relevant cost driver

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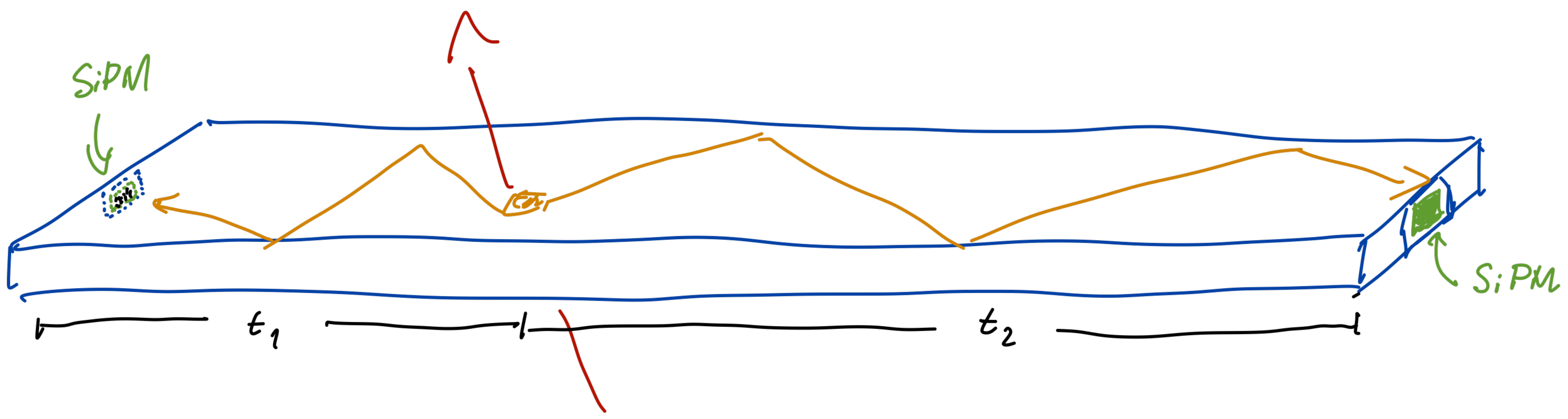
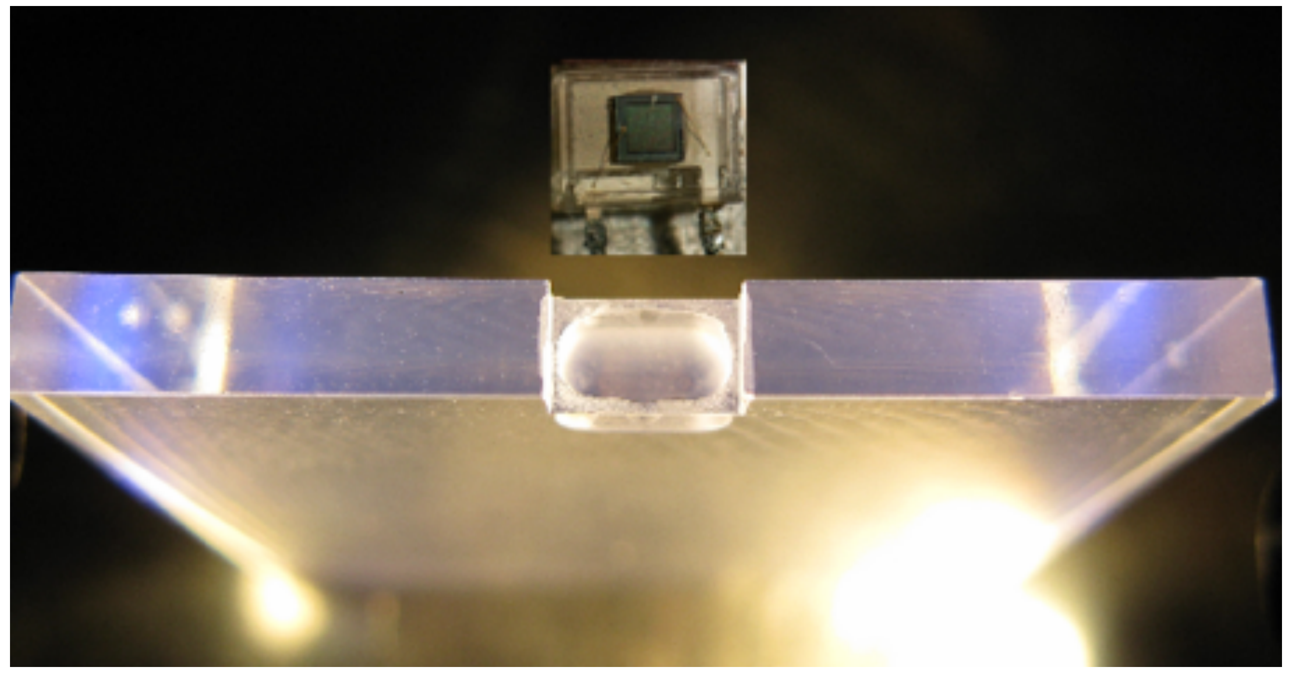
➩ Consider strips with direct readout at both ends - position resolution within strip via timing

- 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



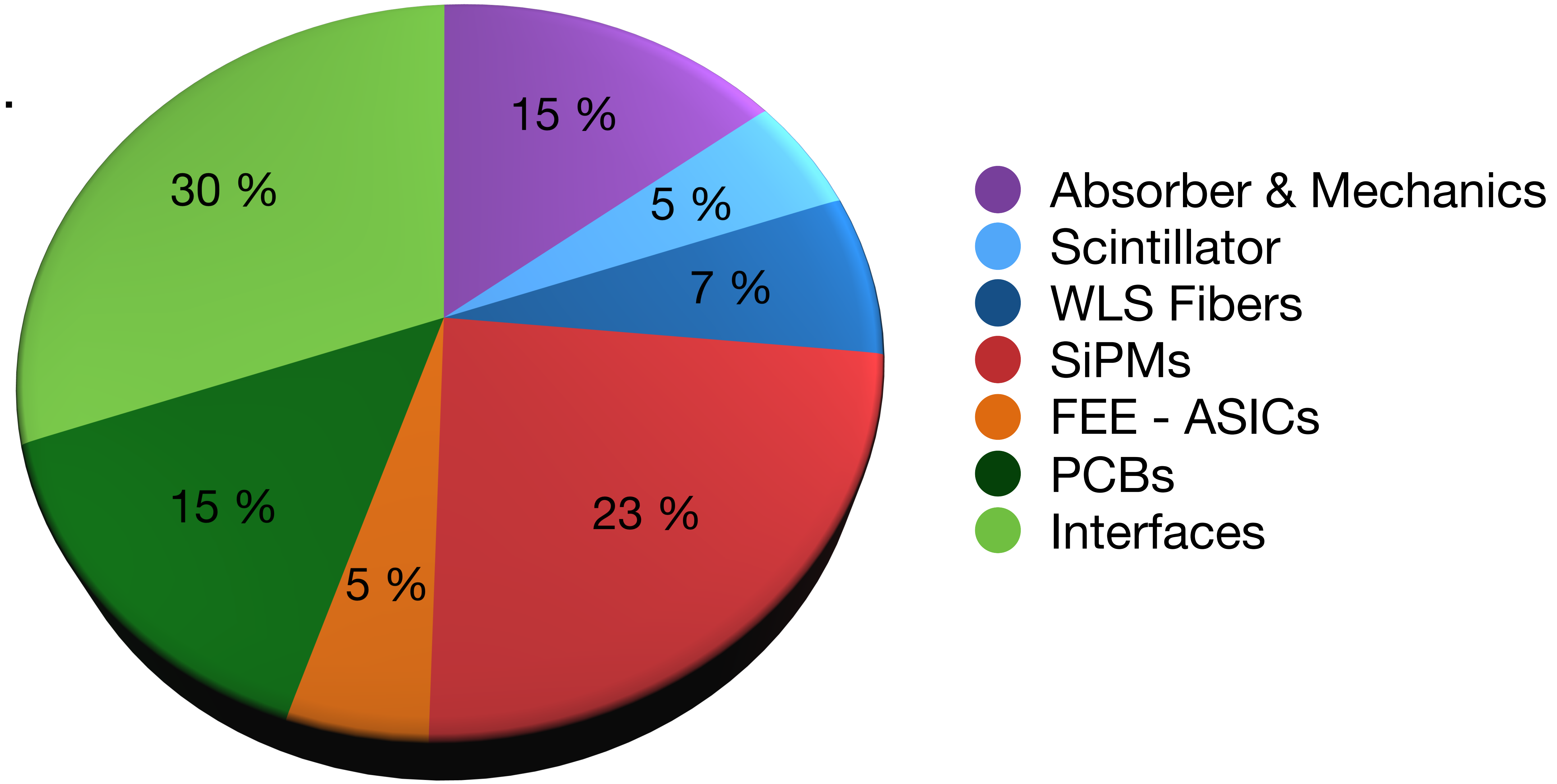
Profit from earlier studies of direct side coupling at MPP



A Few Words on Cost

Without concrete numbers - work in progress

- Based on the current design presented by Eldwan (8 HG, 72 LG layers DS, 6 HG, 54 LG layers US)
  - Results in ~3.3 M channels, ~ 90% in the HG elements
  - Cost estimates based on CALICE AHCAL, CMS HGCAL, Belle II KLM,…



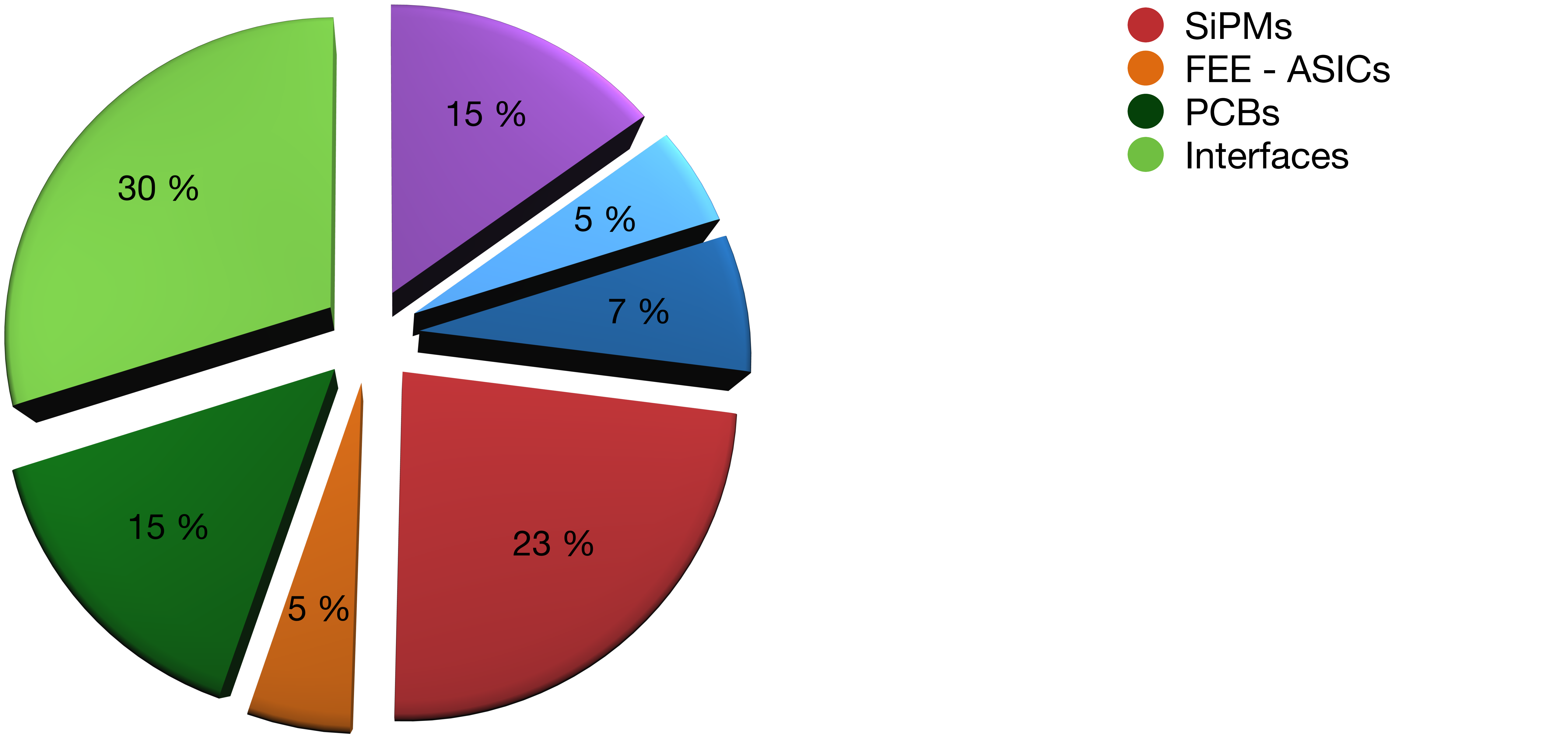
- Size matters:
  - ~ 35 m^3 absorber (when using Cu)
  - ~ 85 m^3 scintillator
  - ~ 400 km fibers
  - ~ 1900 m^2 PCB for HG layers

- 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”

A Few Words on Cost

Zooming in on scaling expectations



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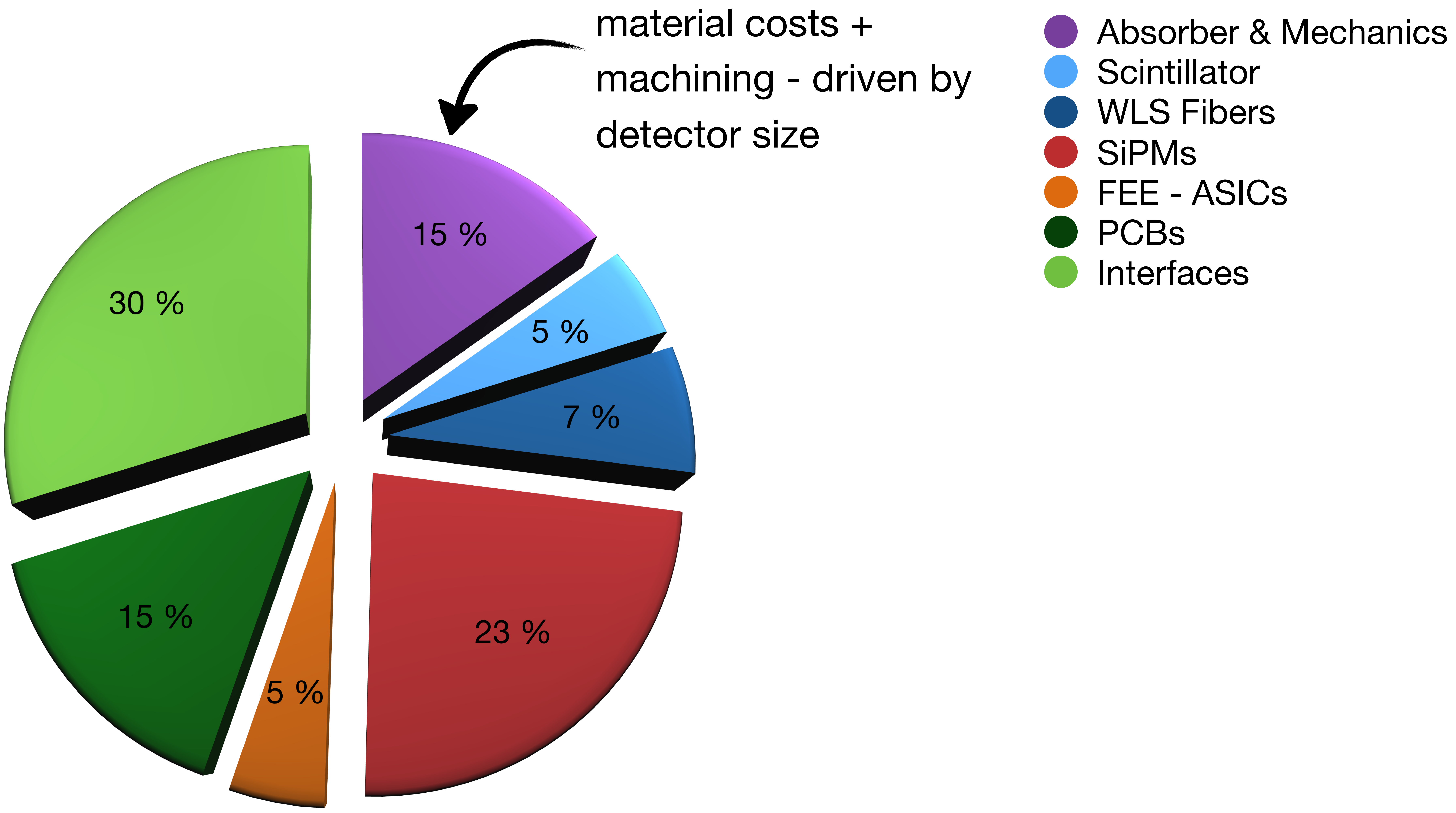

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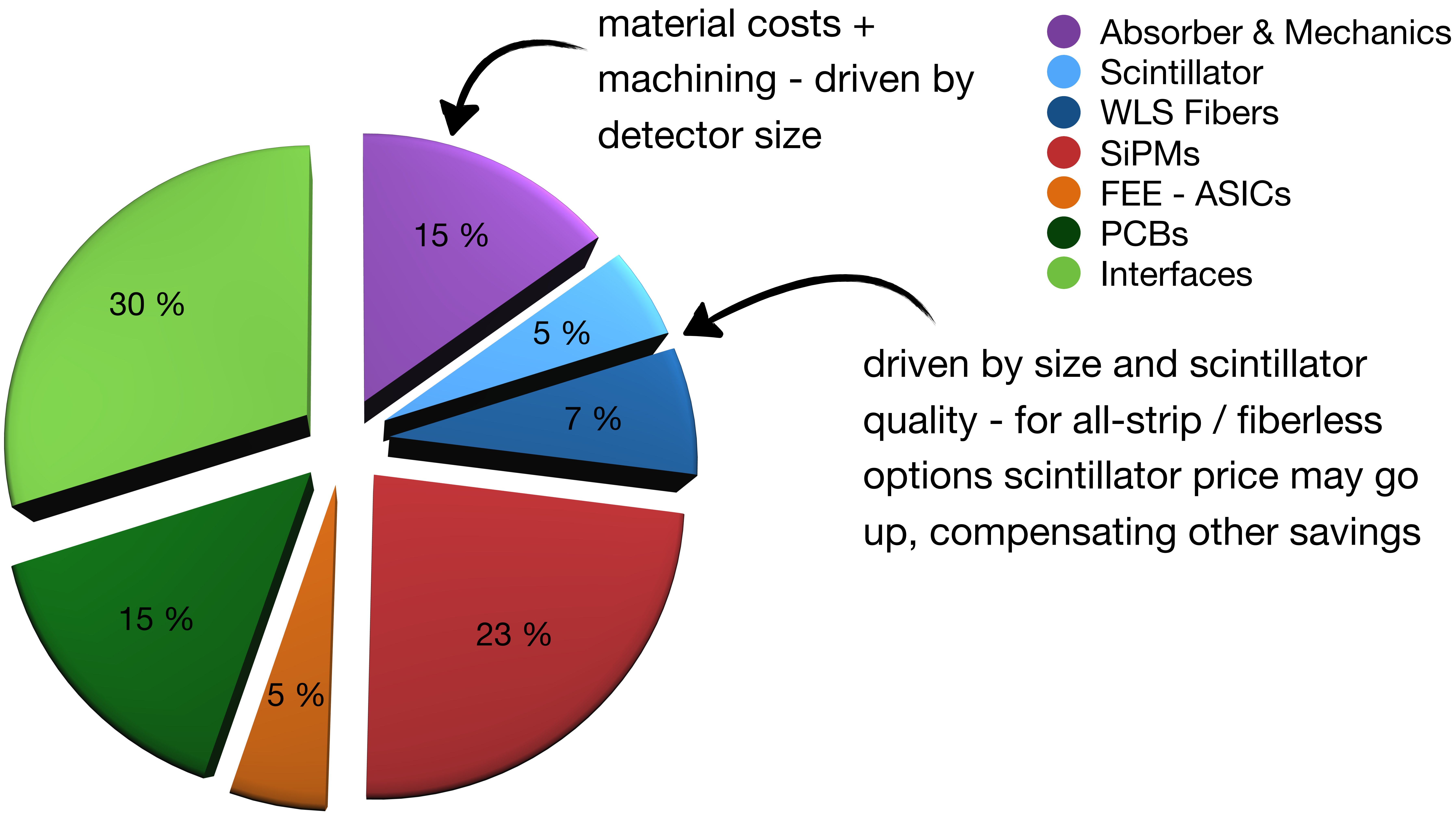

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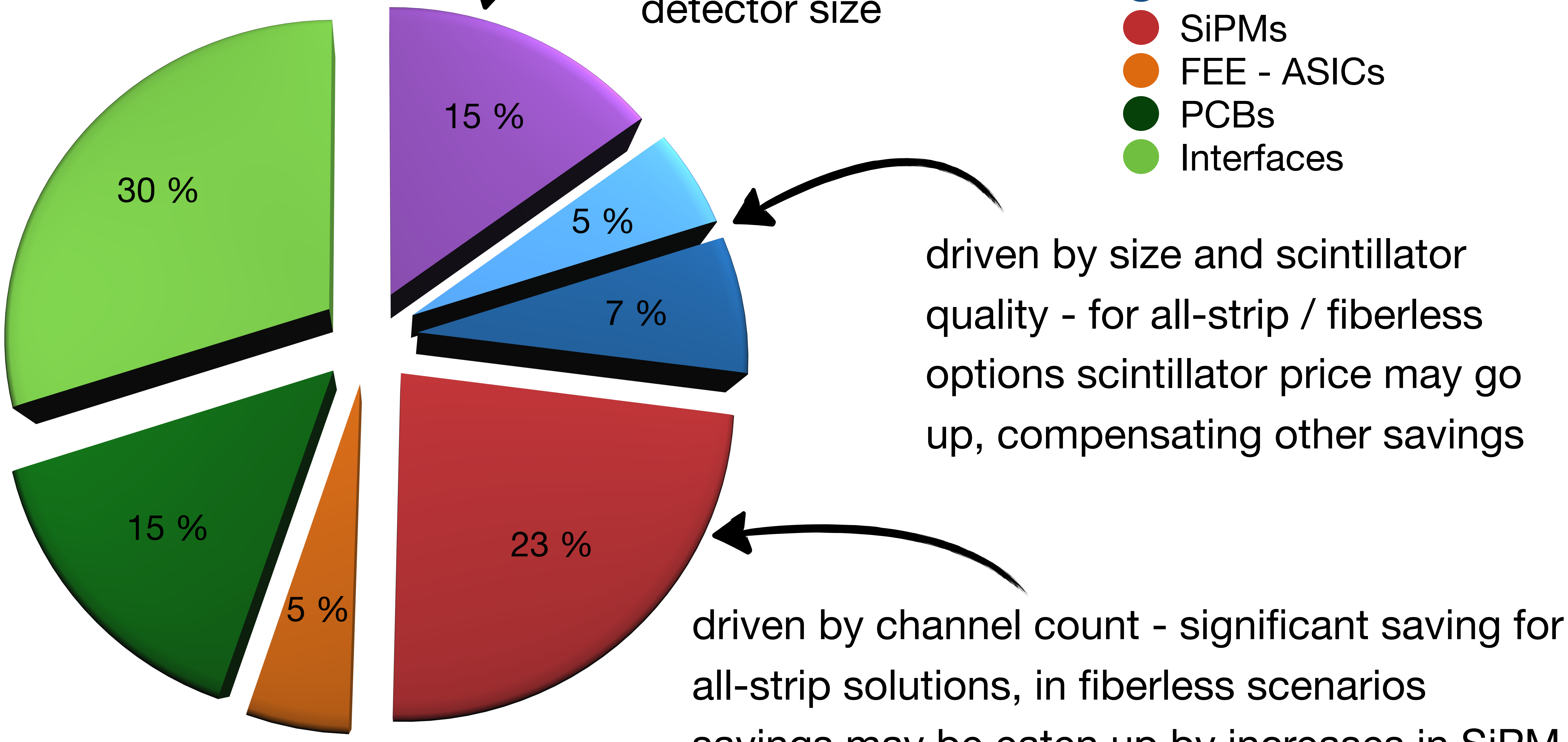

material costs + machining - driven by detector size

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

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

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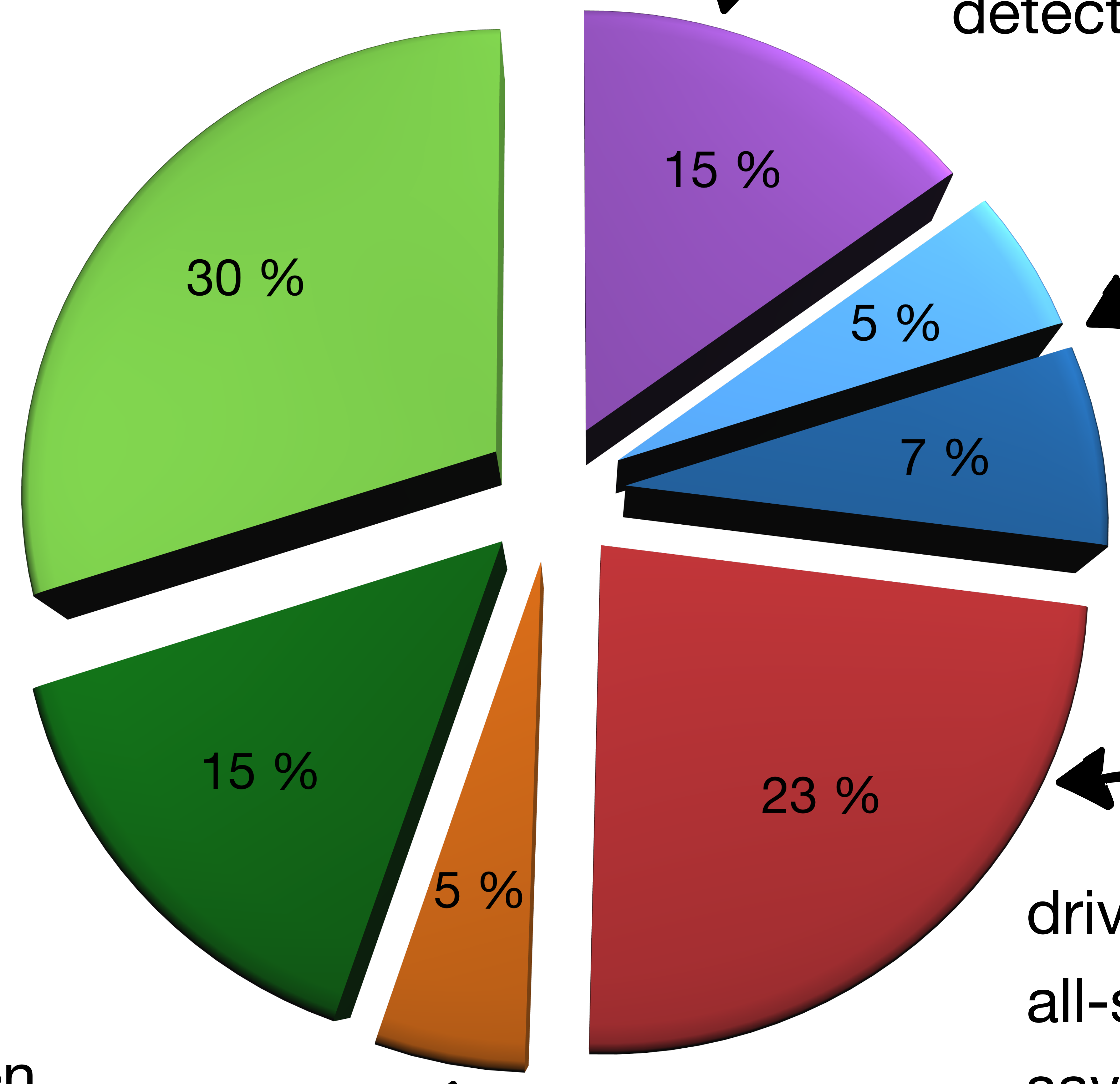

- Absorber & Mechanics
- Scintillator
- WLS Fibers
- SiPMs
- FEE - ASICs
- PCBs
- Interfaces

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ASIC + associated costs driven by channel count + cost pedestal

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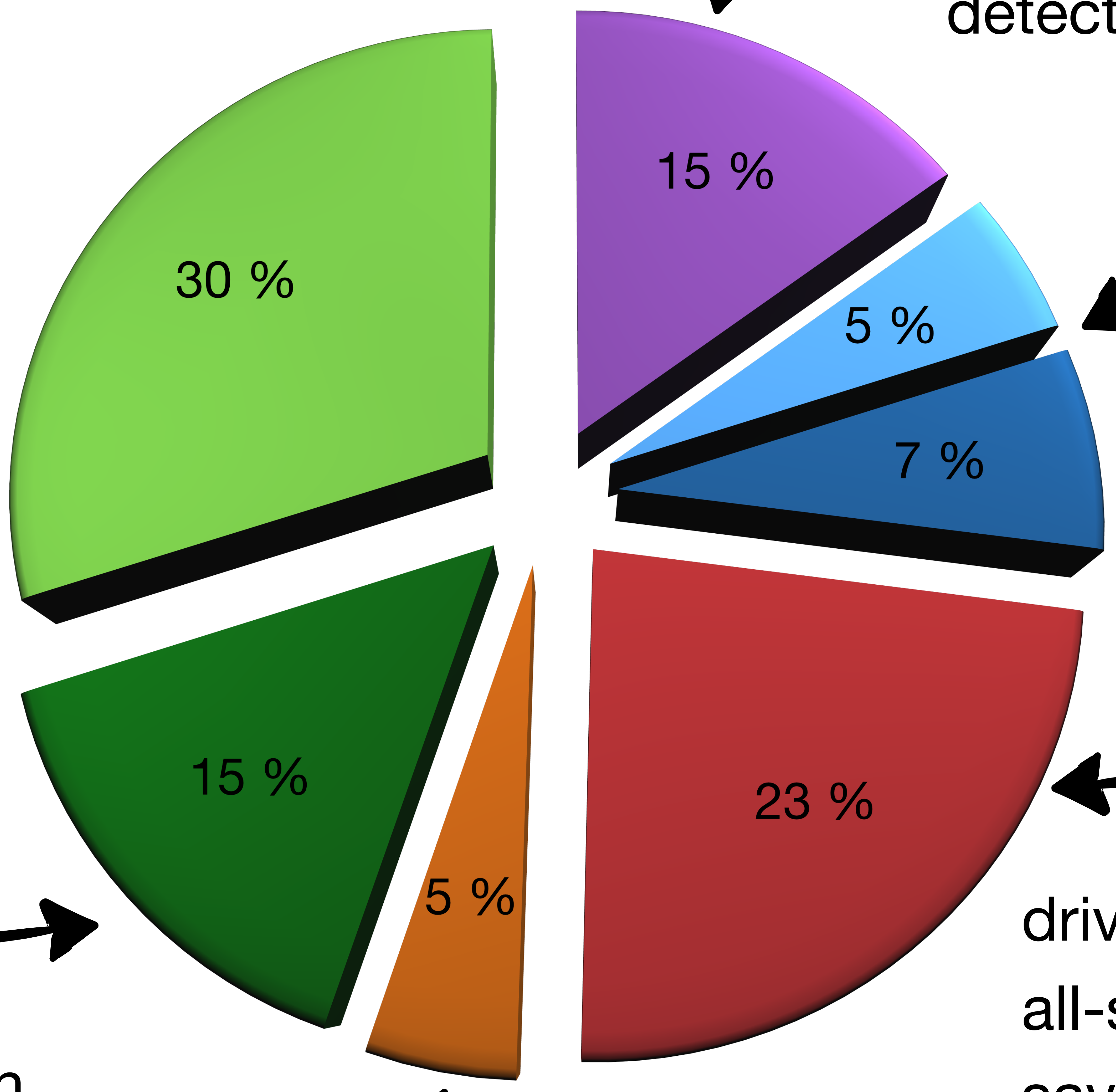

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PCB for HG elements - driven by area (= number of layers) of HG elements

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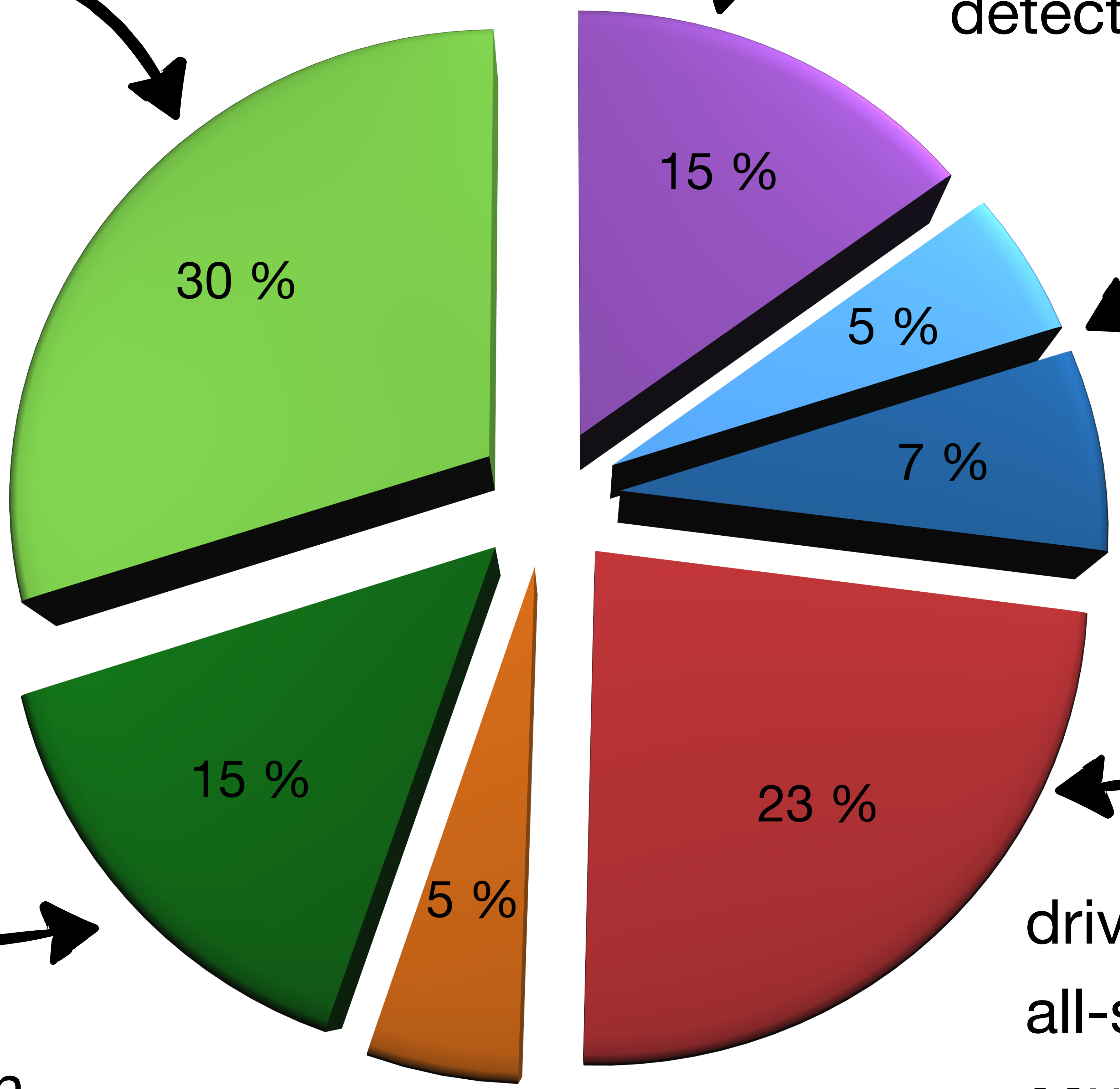
Interfaces (data collection, calibration, control) - at present driven by number of layers - significant savings possible for non-HG layers by grouping layers

material costs + machining - driven by detector size



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Upcoming R&D activities

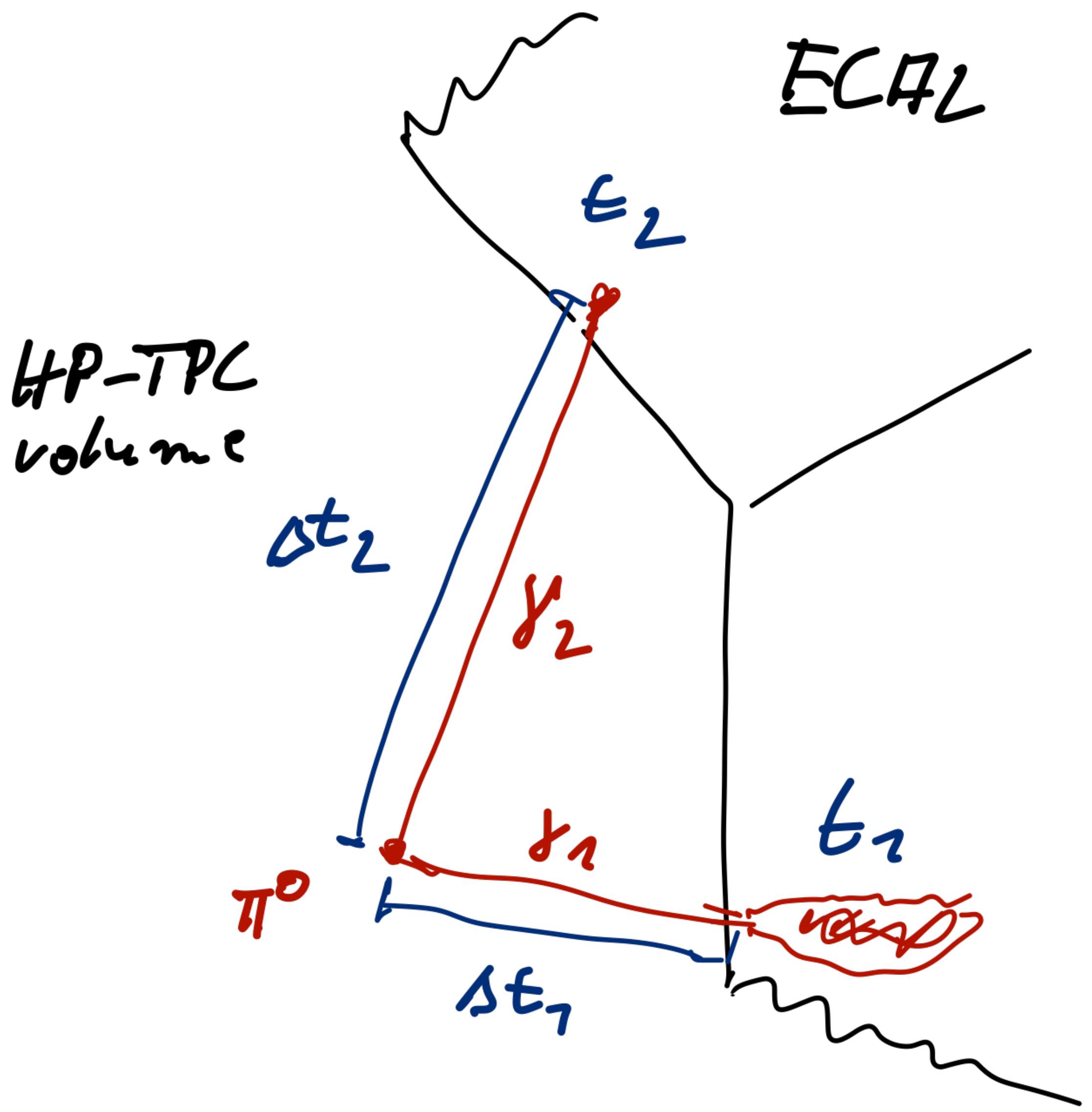
The path forward

- 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”

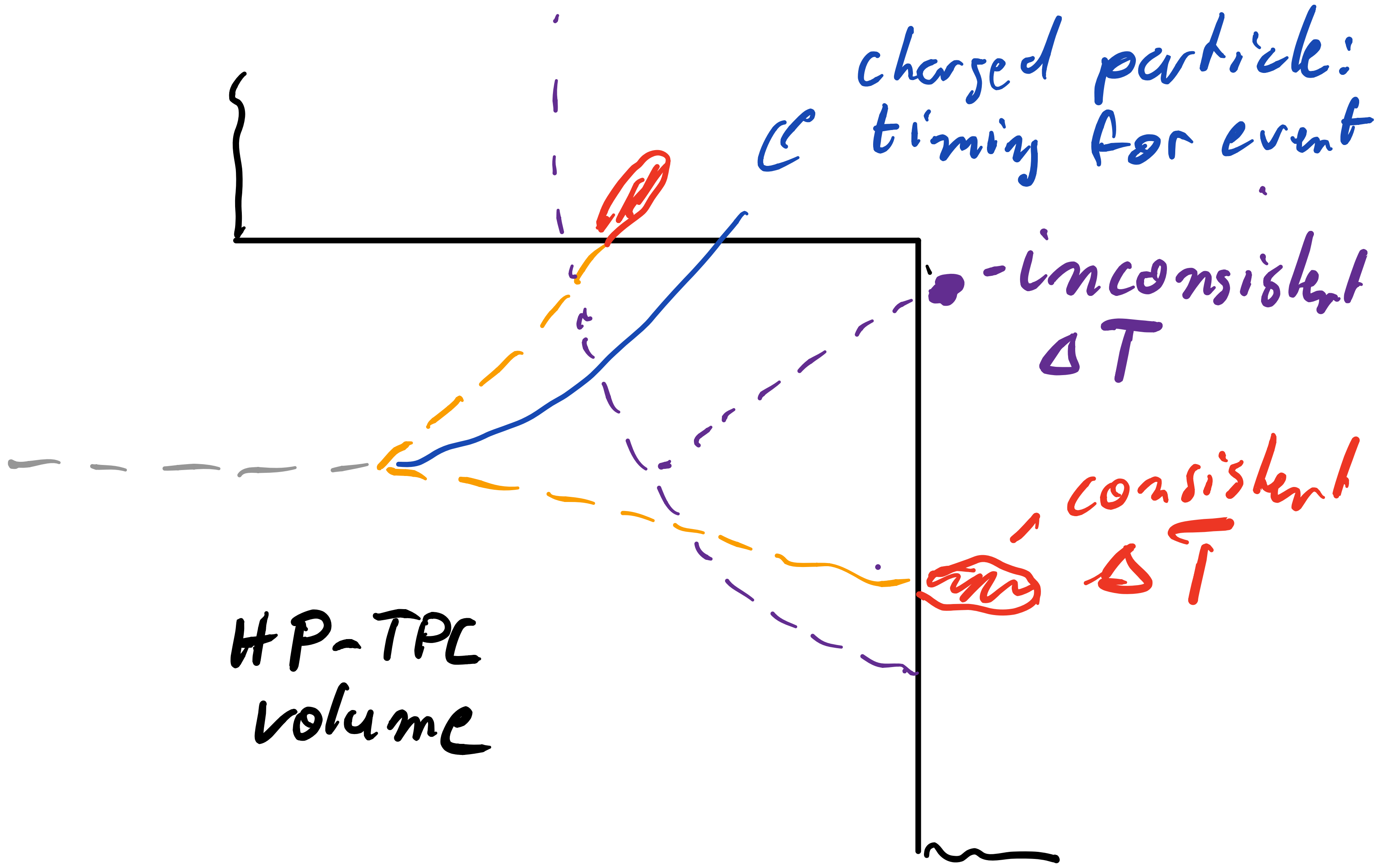
In first MPP studies:
direction + energy of cluster
(challenging for low energies!)

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



- On the hardware side:
  - Start exploring strip options
  - Possibly investigate boron-doped scintillators as a possibility to boost low-energy neutron sensitivity
  - …

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- And, last but not least: Need to get the ECAL on the real axis