Longitudinally separated Forward HCal (LFHCal) Simulation Update

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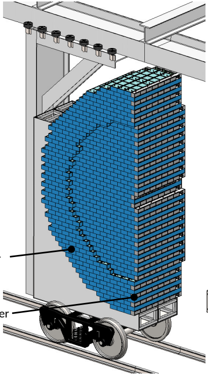
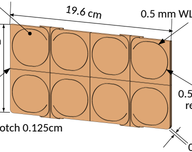
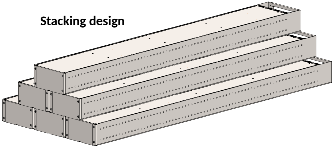
Executive Summary

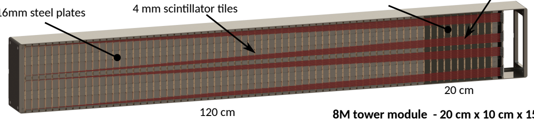
- Focussing on options 1b (LFHCal with burried SiPMs) & 2 (GFHCal)
- Progress on LFHCal:
  - Simulations assumed to perform the same between option 1/1b increased realismn of simulations
- Progress on GFHCal:
  - Improving realism of GFHCal (digitization, clustering, geometry)
  - Understanding where significantly reduced performance originates
- Too strong simulataneous dependence on φ & η for GFHCal performance will not pursue this design option any further

Option 1 (WLS fibers)





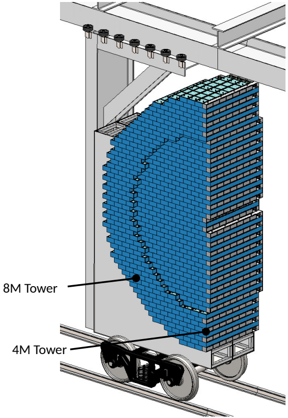


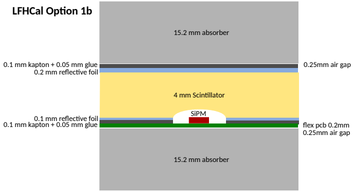


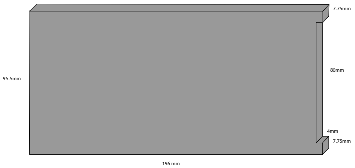
Concept:

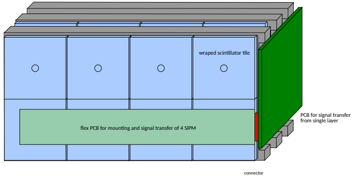
- PSD [link TDR] inspired inspired Fe/W-Scint calorimeter
  4 layers of W (160 mm)-Sci plates (4mm)61 layers of Steel (160 mm)-Sci plates (4mm) +
- Multiple towers combined in one module to reduce dead areas, increase granularity
- WLS fibers running into each tile, read out at the end
- Read-out:
  - 7 signals per tower (signals combined from 10 Sci-plates, 5 in tungsten section)
  - 63.3K channels read out
- Modules of different sizes (8M, 4M, 2M, 1M) to maximize coverage & assembly efficiency

Option 1b (Buried SiPM)



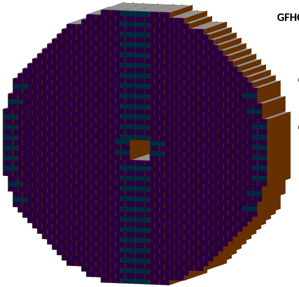


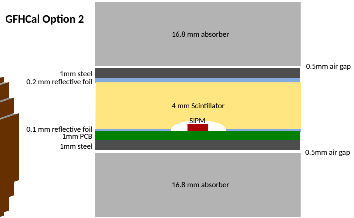


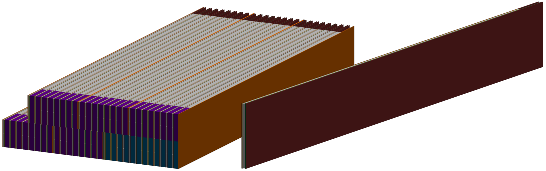


- Same general design as LFHCal option 1 replacing WLS fibers in each layer with SiPM on tile option and single wrapped tiles (5x5cm)
- Transfer of signals via small flex PCB to side of 8M module + long PCB to the end
- Signal summing of individual SiPMs at the end, same readout granularity at the end
- FEB boards removable similar to option 1, SiPMs not
- Simplified machining of absorber plates
- Upgrade option 1b+: Readout every SiPM by adding more HGCROCs & removing summing board, liquid cooling would be needed

Option 2 - GFHCal





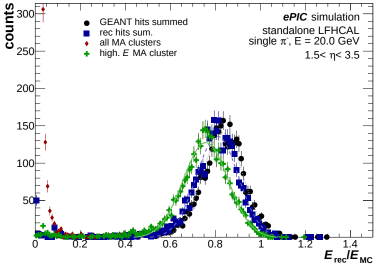


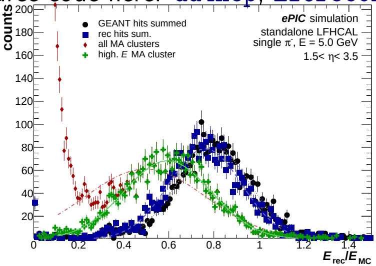
- Outer module dimensions + stacking stay largely the same replacing 4M with 12M modules
- Internal module design rotated by 90° absorber running in z direction
- Electronics + Scintiallator tiles pulled out towards the back in cassets
- SiPM on tile option with 5x5cm tiles
- Transfer of signals via long flex PCB to the end
- HGCROCs sitting in the back of HCal, cooling needed only in the back
- Signal summing of individual SiPMs at the end (2 tiles each) $\rightarrow$ increased granularity
- Simplified machining of absorber plates compared to option 1
- Upgrade option 2b+: Readout every SiPM by adding more HGCROCs & removing summing board, more liquid cooling would be needed

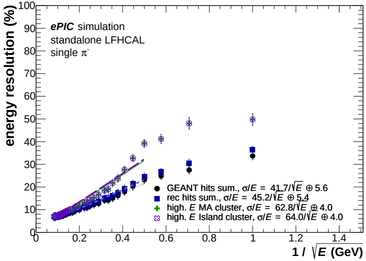
Simulation updates

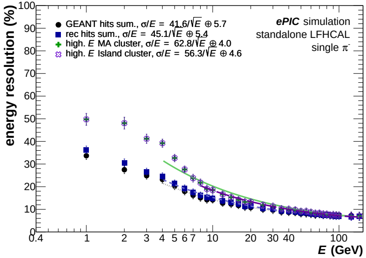
LFHCal simulations

source code here: dd4hep, EICrecon



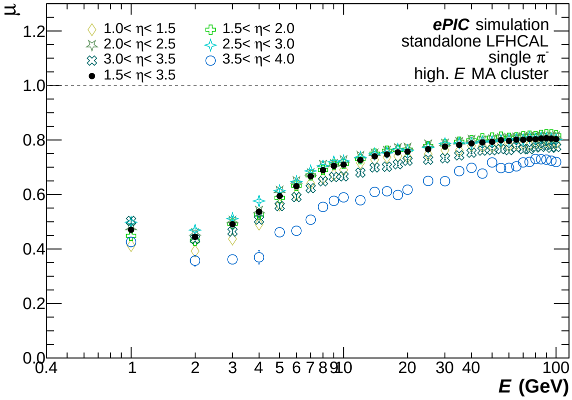


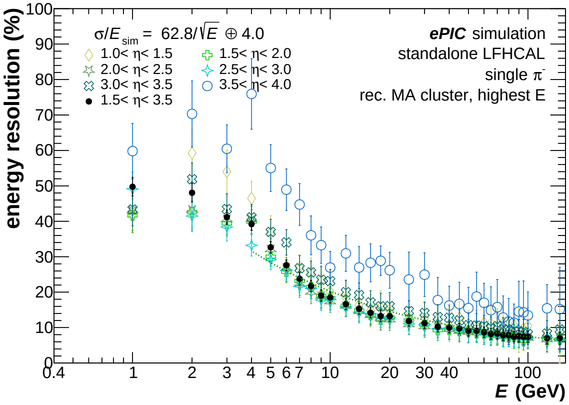




- Full implementation of hit chain (including basic noise simulation) & first version of clustering
- All simulations done with only HCal & single particle simulations
- Resolution calculated with time & energy cut offs
- Fitting restricted to > 4 GeV (as for CALICE data) resulting in more realistic $1/\sqrt{E}$- term

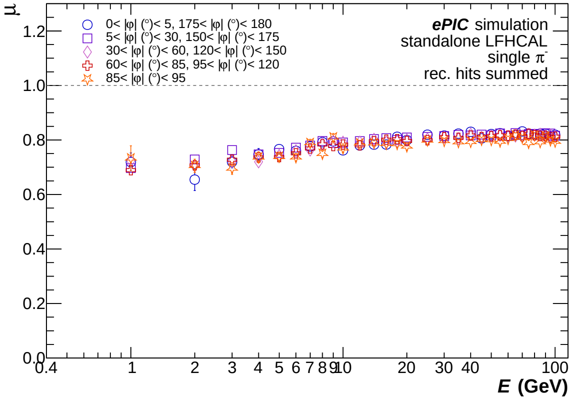
LFHCal simulations vs η

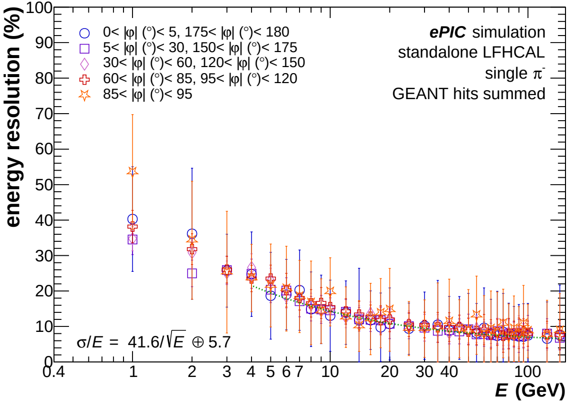




- Current implementation without insert
- Mild η dependence $1.5 < \eta < 3.0$
- Small leakage seen for $1.0 < \eta < 1.5$ & $3.0 < \eta < 3.5$, significant losses beyond $\eta = 3.5$

LFHCal simulations vs φ

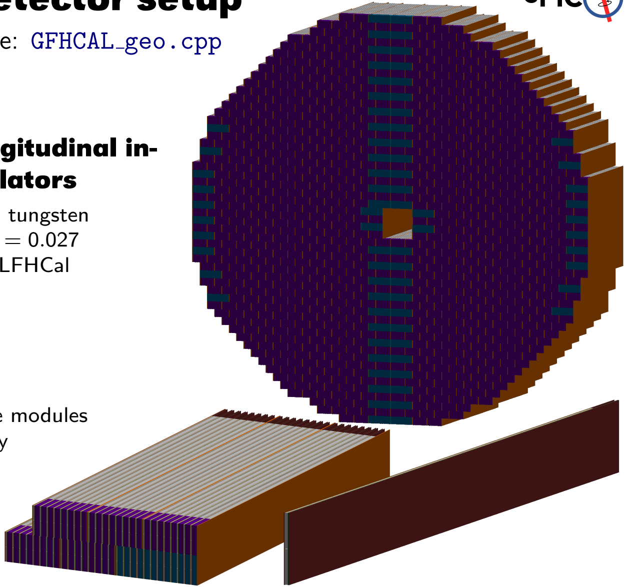




- Current implementation without insert
- No φ dependence

gFHCal detector setup

source code here: GFHCAL_geo.cpp

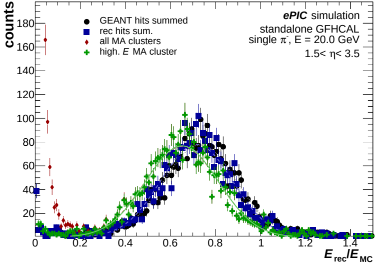


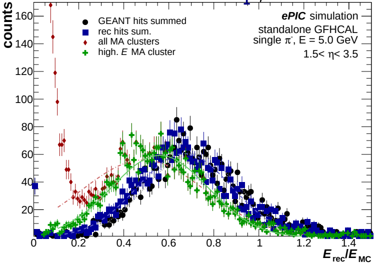
Alternative forward HCal design with longitudinal instead of transverse absorbers and scintillators

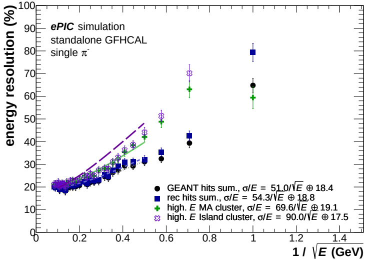
- Longitudinal absorber plates 120cm steel and 10cm tungsten
  → 16.8mm thickness, average sampling fraction: $f = 0.027$
  → additional version with more layers: $f = 0.036$ (LFHCal $f = 0.033$)
- Longitudinal 0.4x5x10cm^3 Scintillator tiles
- Removable Scintillator+pcb mini frames
  → 1mm PCB space in current simulation
- Detector made of 20x10cm and 30x10cm front face modules
  → violet and cyan colors in right figure, respectively

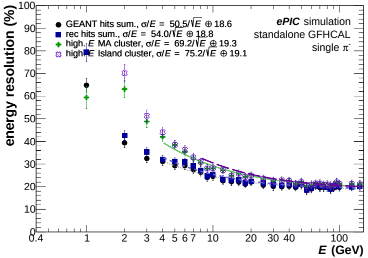
GFHCal simulations

source code here: dd4hep, EICrecon



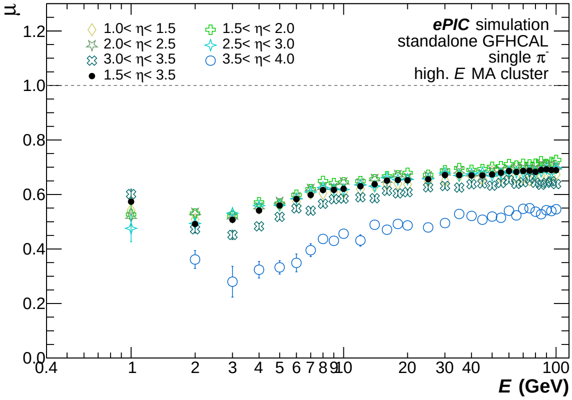


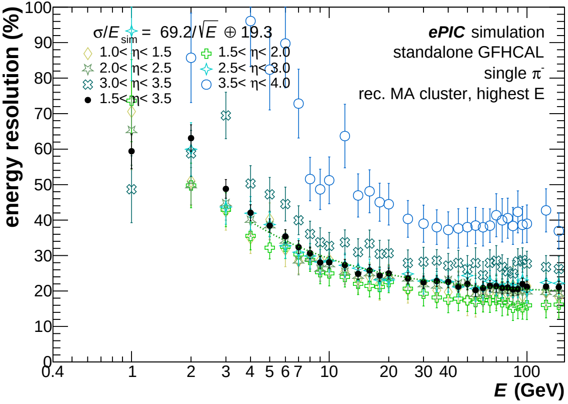




- Full implementation of hit chain (including basic noise simulation) & first version of clustering
- All simulations done with only HCal & single particle simulations
- Resolution calculated with time & energy cut offs
- Fitting restricted to $>$ 4 GeV (as for CALICE data) resulting in more realistic $1/\sqrt{E}$- term
- Significantly larger constant term than for LFHCal

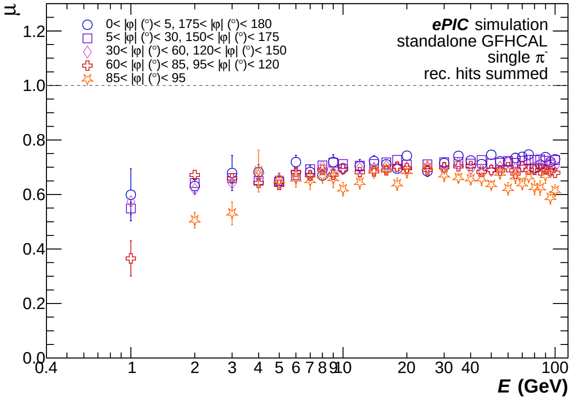
GFHCal simulations vs η

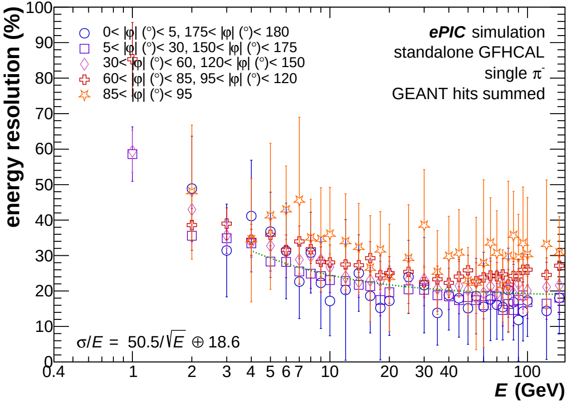




- Current implementation without insert
- Mild η dependence $1.0 < \eta < 3.0$
- significant losses beyond $\eta = 3.0$, as expected

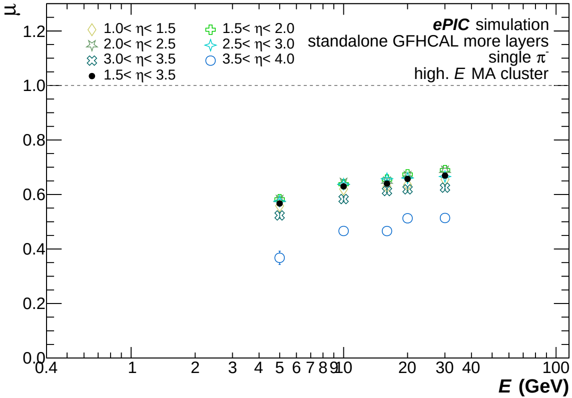
GFHCal simulations vs φ

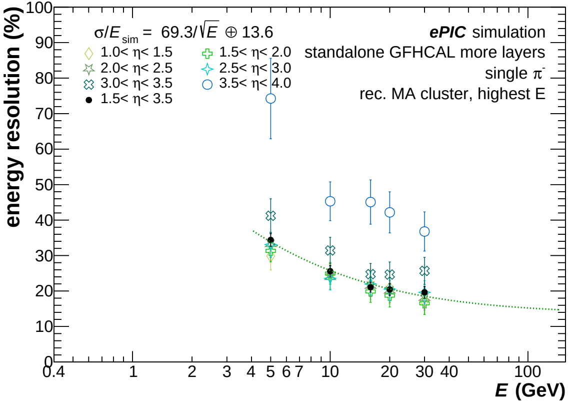




- Current implementation without insert
- Strong φ dependence, as expected (orange along y-axis, blue along x-axis)

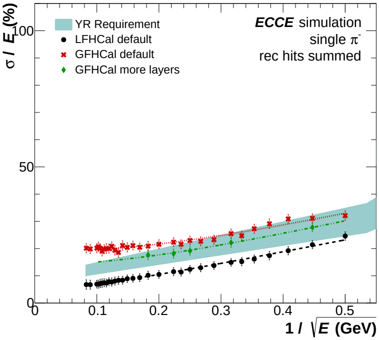
GFHCal simulations (m. layers) vs η

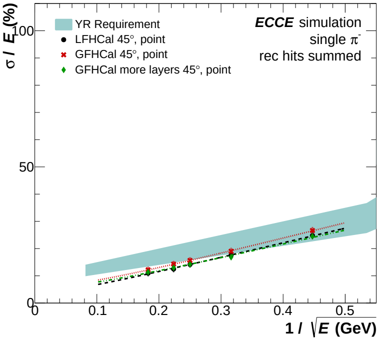


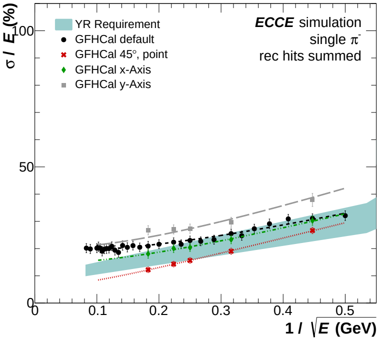


- Current implementation without insert
- Mild η dependence $1.0 < \eta < 3.0$
- significant losses beyond $\eta = 3.0$, as expected
- Improved constant term compared to default setup

Understanding the simulations (1)



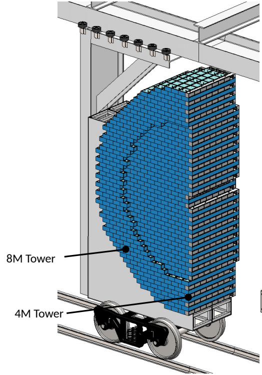


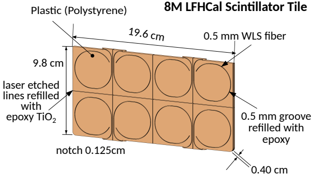


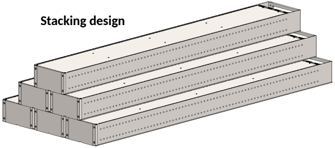
- Left: Comparison of different detector setups full η/φ
- Middle: Comparison of different detector setups at 45∘ in center of detector
  very similar performance GFHCal more layers & LFHCal
- Right: Comparison of default GFHCal in different regions
  Significant losses along y-axis (channeling) and even along the x-axis
  Particle hitting center of detector similar performance as LFHCal

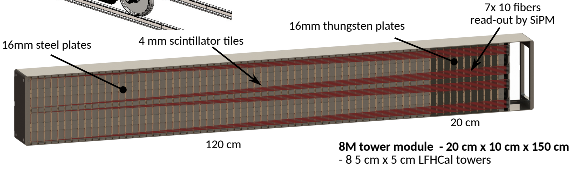
Backup
Different Options

Option 1 (Default)









Concept:

- PSD [link TDR] inspired inspired Fe/W-Scint calorimeter
  4 layers of W (160 mm)-Sci plates (4mm)61 layers of Steel (160 mm)-Sci plates (4mm) +
- Multiple towers combined in one module to reduce dead areas, increase granularity
- WLS fibers running into each tile, read out at the end
- Read-out:
  - 7 signals per tower (signals combined from 10 Sci-plates, 5 in tungsten section)
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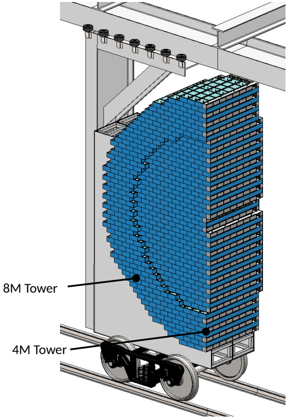
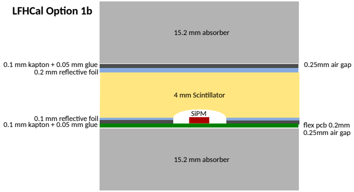
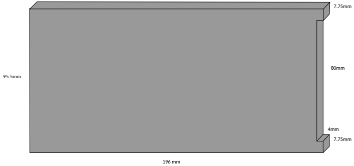
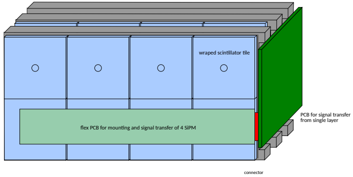
Option 1b (Buried SiPM)









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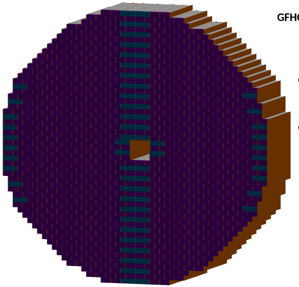
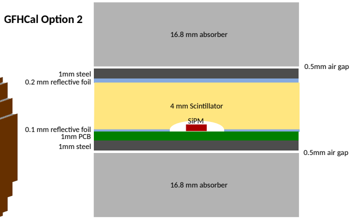
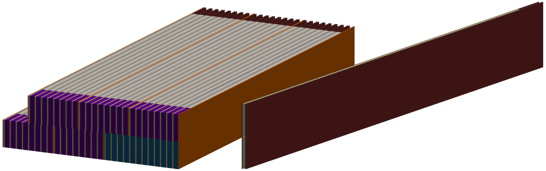
Option 2 - GFHCal







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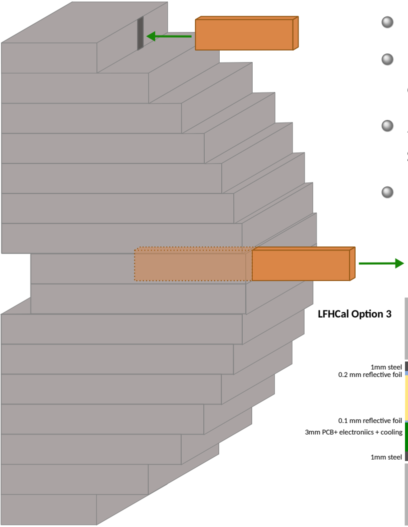
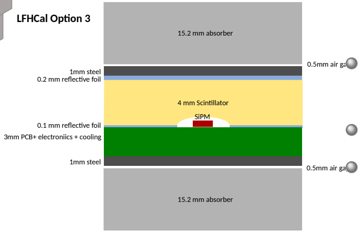
Option 3 - Full casset design

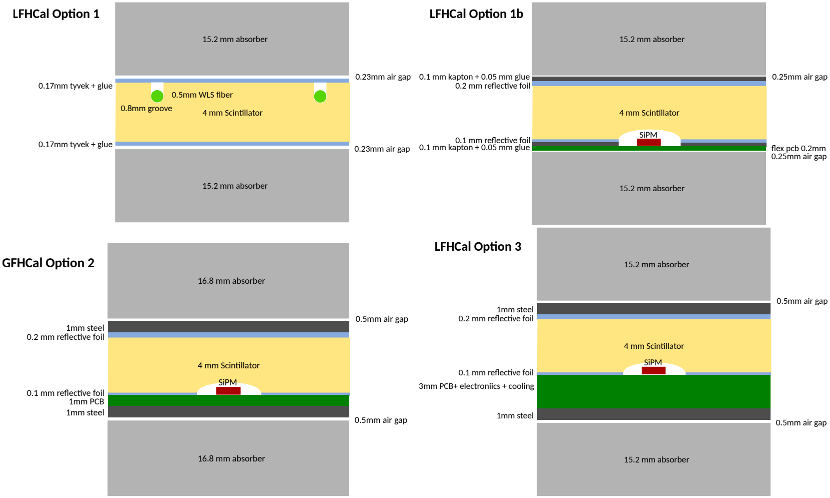


- Full redesign of everything
- Closest concept to HGCCal or CALICE AHCal SiPM on tile (5x5cm) & could incorporate insert with higher granularity
- Absorber structure of half detector (shell) + cradle build as a whole with slots on side for insertion of cassets
- Cassets $\sim$ 30cm x 250cm in worst case (center) with all scintillators + readout electronics inside



- HGCROCs would need to be integrated in layers
- Cooling absolutely necessary in layers
- Electronics + SiPM servicable no ganging trivially possible

Comparison layer thickness



- Due to different needs, i.e. connections, cooling, readout out significant differences in sampling fraction
- Can't be fully adapted by changing layer thickness of steel/thungsten

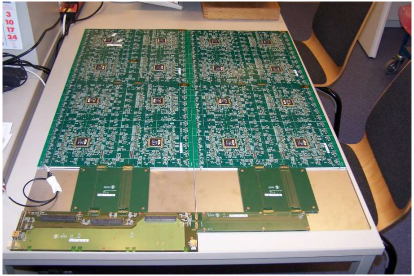
Electronics comparsion

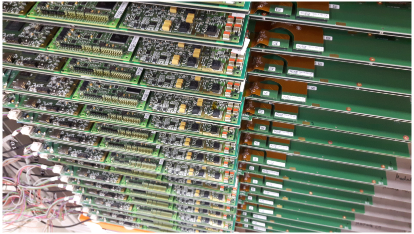
	Option 1	Option 1b	Option 1b+	Option 2	Option 3
Channel #	63,280	63,280	601,160	253036	601,160
SiPM $	63,280; 3x3mm 506	601,160; 1.5x1.5mm 4210	601,160; 1.5x1.5mm 4210	506,072; 1.5x1.5mm 3550	601,160; 1.5x1.5mm 4210
Summing board	No	Yes (10channel)	No	Yes (2channel)	No
# HGCROC (FEB) k$	~1,100 22	~1,100 22	~10,450 210	~4,500 90	~10,450 210
ECON-D (FEB) k$			1,800 9	750 1.5	1,800 9
FPGA (RDO) k$	46 90	46 90	90 180	37 150	90 180
PCB	135	135	270	113	270
Cooling	0	back	back	back/inner	inner
Cables, etc	?	?	?	?	?
Total cost k$	753	4457	4880	3829	4880

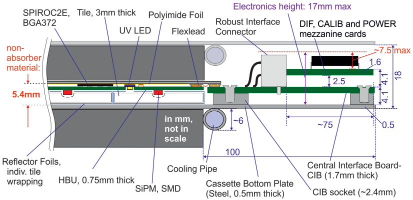
Main Questions option 1b & 2

- Can one drive & readout the SiPM over > 1m using PCB or capton flex without applification?
- If not cooling might become necessary
- Do we wanna gang SiPMs
- Do we wanna go for injection molded tiles‘?
- For option B, what does it to the physics?

Additional infos from CALICE & CMS







CMS:

- In full cryo container, liquid Nitrogen
- No possibility to service HGCROCs or SiPMs ever

AHCAL:

- Cassets with fully integrated electronics $\sim$ 6mm on inside, 3mm electronics
- Clearance around casset $\sim$ 1 mm on both sides