The AIDA-2020 Advanced European Infrastructures for Detectors at Accelerators project has received funding from the European Union’s Horizon 2020 Research and Innovation programme under Grant Agreement no. 654168.

This work is part of AIDA-2020 Work Package 14: Infrastructure for advanced calorimeters.

The electronic version of this AIDA-2020 Publication is available via the AIDA-2020 web site http://aida2020.web.cern.ch or on the CERN Document Server at the following URL: http://cds.cern.ch/search?p=AIDA-2020-SLIDE-2019-003

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CALICE/ILD SiW-ECAL
a 26 Layer Model and 1\textsuperscript{st} Tests of a Long Slab

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LCWS 2018
23.11.2018, Arlington (TX)

TNA support + WP14
Introduction

SiW-ECAL ~ 30% of ILD costs (ILD Models of SiW-ECAL: LoI, DBD) and most sensitive calorimeter (1/3 – 2500 mips, auto-trigger, high density)

1) How to reduce costs without impact (too much) performance?

- \( R_{\text{ INNER ECAL}} = 1842 \text{mm} \rightarrow 1462 \text{ mm: in simulations} \)

- 30 → 26 layers
  - 8”, 725\( \mu \text{m} \) wafers

2) Recent progress in feasibility studies:

- Base unit «ASU» ~ validated
  - almost validated (see Adrián's talk): on beam test data: uniformity, noise, auto-trigger perf. Response low \( E \) and high \( E \) to be assessed
  - Updated version → FEV13 design by Taikan

- 1st prototype of a long slab (this presentation)
Redefinition of dimensions

2 designs to be looked at:

- a “baseline” (or “large”) with inner ECal radius at RECal = 1804 mm, (model close to the DBD)
- a “small ILD” model $R_{ECal} \sim 1500$ mm (all related quantities adapted $\leftrightarrow R_{outer[Endcaps]}$)
- Plus a model with slightly reduced number of layers = 26 layers (wrt 30).

Under work version of **ECal Technical Design Document** (TDD, 96 pages)
by Henri Videau (LLR), Marc Anduze (LLR) and Denis Grondin (LPSC) (+ ed. Daniel Jeans & Roman Poeschl) available on
https://llrbox.in2p3.fr/owncloud/index.php/s/eeVeAlyv8o27VRF

Small ILD with 26 layers → §5 of TDD.
Dimension constructions (reminder)

Barrel length fixed at **4700mm** in all models, same as HCal or TPC

- 8 staves $\supseteq$ 5 CF/W modules $\supseteq$ 5 alveoli columns
- 1 alveoli width = $\sim 2 \times$ wafers width + walls + clearance $\sim$ **187.4mm**

Endcaps

- $Z_{\text{front EndCaps}} = Z_{\text{outer Barrel}} +$ overlap (62mm for Services + Security)
- $R_{\text{INNER EndCaps}}$ fixed at 400mm $\Rightarrow$ ECal ring
- $R_{\text{OUTER EndCaps}} = R_{\text{INNER EndCaps}} + n$ alveoli (+ wall, clearance)
- $R_{\text{OUTER Barrel}} = R_{\text{OUTER EndCaps}} -$ overshoot

Baseline

- Endcap quadrant with 3 modules of 3 alveoli

Small

- Endcap quadrant with 2 modules of 4 and 3 alveoli
**ECal thickness**

**DBD thickness:** 185 mm, “hopelessly aggressive”

More realistic calculations

- **223.2 mm** (Δ = +38.2 mm) for barrel
- **223.6 mm** (Δ = +38.6 mm) for endcaps

For thin layers (×2 for thick ones)

- Connection & capa
  - was 320μm
  - was 0.8mm
  - was 0.2mm
Small ILD

Same recommendations as for baseline:

- recalculated $R_{INNER}^{HCAL, BARREL}$ as $1500 + 185 + 30 = 1715 \text{mm}$

Small ILD ECal dimensions:

- $R_{INNER}^{ECAL, BARREL} = R_{INNER}^{HCAL, BARREL} - 30\text{mm} - 223.2\text{ mm} = 1461.8\text{mm}$
- $Z_{FRONT}^{ECAL, EndCaps} = 2411.8\text{ mm}$ (unchanged from baseline)
- $R_{OUTER}^{ECAL, EndCaps} = 1717.2\text{ mm}$
  - 2 modules per quadrant of 4 (inner) and 3 (outer) alveoli
  - The overshoot of the end-cap to the barrel is then 32mm
Going to 26 Layers: performances

Going from 30 to 26 layers

- Reduction of cost; increase of Energy resolution
  - keep $24X_0$ (84mm) of Tungsten

Increasing the Si thickness to 725μm

Energy resolution $\sigma(E)/E$:

- for 26 layers w.r.t. 30: $\gtrsim +8.5\%$
- with 725μm w.r.t 500μm: $\lesssim -6.6\%$ (-8.7% wrt to DBD 300μm)

\textbf{near compensation}  

Study needed on dead zones (larger GR...), separation, resolution and efficiency performances at low energy.

- eg: JER : $\sigma(E_J)/E_J +6\%$ for 26 layers (500 μm) to be redone...

\textit{Shown @ 6th ILD Optim meeting (16/07/2014) [link]}
26 layers: dimensions

ECal thickness:

- 26 layers = 18 ‘simple’ layers with 2.47mm of W  
  + 8 ‘double’ layers with 5.6mm  
  shared between structure and slabs (4.94mm of W)
  
  → 211.9 mm (wrt to 223.9 for 30 layer model)

- → relaxed constraints on
  
  • clearance margin inside alveoli: 2×0.1mm → 2×0.2mm
  
  • chip packaging: 0.8mm → 1.0mm
  
  • PCB thickness: 1.0mm → 1.1mm

Total: 223.2mm → 222.2mm + 1mm clearance
150 mm (6’’) Wafers

DBD like wafers on 150mm ingot
54 % use of surface

18×18 pads

Pad size = 5.08mm
(prototype = 5.5mm)

18×21 pads

optimized use: → 63–75 %

Tiling in barrel
Going to 200mm Wafers...

From CMS HGCAL development & Hamamatsu contacts
future is 200mm (8") ingots, 725μm thickness

Mechanical constraints → ~187 mm alveoli, ~12 cm wafer

→ 1.5 Wafers ⊗ cell # mult. of 3 ⊗ cell width ~5 mm ⊗ paving with ~64ch ASICs

→ 30 or 36 cells in width

Optimised ReadOut electronics

- 6x6mm², ASICs of 60ch.

wrt 5x5mm² (≠5.5² of prototypes)

30% less electronics consumption cost

- ASU: 1440 pads, 24 ASICs

- Noise ~ C / width²/th. ~ cst,
  Signal ~ th ➔, S/N ~ ×1.5;
  depl. Voltage ~ th² (×2)

⇒ Improved timing perf (esp. for mips)

wafers on 200mm ingot ; 63 % use of surface
Tiling with 200mm (8’’) wafers

Matching of large and small rectangles, triangles and diamonds to be detailed for optimal use

add’l small rectangles:
87 % use of surface
(83 % for an hexagonal shape)
Reduced gaps

90°

Mean of weighted energy distribution

gap_0mm

10 GeV, 1.5 ≤ θ ≤ 1.65

Reduced alignment of inter-wafer gap

Possible additional reduction of inter-slab alignments
SLAB « long » (≤12 ASU)
- Partie électronique + Baby W. (Signals, Power P.)
  ⇒ Design Realistic SLAB

2018

Prototype technologique (1 ASU)
Tests au DESY (8 layers)
& CERN (10 layers ≥ 4 FEV13, 650μm)

S/N_{Trig} ~ 12
1st “electric long slab”

Scale to support electronics
- Support of interface boards + 12 ASUs (DBD)
- 2+6+4 ASUs = ~3.2 m
- Total access to upper and lower parts
  - 320μm Baby wafers (4×4 pixels) on the bottom

Mechanical characteristics
- Movable: table and to beam test
- Rotatably along long axis (for beam test)
- Rigidity: ≤ ~1 mm per ASU
- No electrical contacts scale / cards

Shielding
- vs Light and CEM

M. Anduze, F. Magniette, J. Nanni, Realisation: G. Fayolle
DESY-2018 beam test

2 weeks beg of July: full test of all prototypes:

- Electric long slab: 8 FEV11 + baby-wafers (320μm 2×2cm²):
- RC Filtering of HV between (every second) boards required
- Very clean response to “mip” (punch through e-)

![Graph showing beam test results](image_url)
Mip analysis

Pixel energy fraction depends linearly on crossing position

Convolution function

$$f(x) = \text{MP}(\alpha) \cos(\alpha)$$

$$\text{MP}(\alpha) = \text{MP}(0) \cos(\alpha)$$

Convolution function

Fit with Mod LanGau function

$$\text{Fit} = \text{modLG} \ast \text{erf}$$

$$\text{modLG}(x, \mu, \sigma) = (1 - e^{-\frac{x^2}{2\sigma^2}}) \ast L(x, \mu, \sigma) + e^{-\frac{x^2}{2\sigma^2}} \ast G(x - t, \mu_G, \sigma_G)$$

Energy deposited in the detector

Simple Geant4 simulation for 5.5mm x 5.5mm, 325 um Si detector
Uniformly bombarded by 3 GeV electrons beam with 60 degree angle
MIP response vs position

mip \( MPV \times \cos(\theta) \) vs ASU#

- OK for 4 1st ASU’s
- Small drop \( \sim 2\% / \text{ASU} \) for \( \geq \text{ASU}#5 \)
- Also hints similar drop on \( \sigma_{\text{ped}} \)

\( \Rightarrow \) Voltage & Gain drop?

Power pulsed mode with ballast et end of slab
(or just random build-up effect from chip variability?)
Conclusions & prospectives

3 models described in detail for the ILD SiW-ECAL: baseline, small, small with 26 layers:

- 725μm thickness with 200mm (8") wafers; 5.08 → 6mm cell size
  - ~ identical photon resolution expected
  - 13% gain cost on Silicon surface, PCB, and 40% on electronics (and power consumption) wrt DBD
  - Improved S/N ratio & timing, less channeling @ 90°

Feasibility improved:

- Single ASU + 1st connexion: S/N ratio, Stability, Uniformity between elements; assessed
  - CALICE technical prototype (11 working ASU as of now)
  - Wafer of 325μm, 650μm tested → 725 μm ? Hamamatsu ✔
  - Others: LFoudry(SMIC), Infineon, Elma, On-Semi
  - Wafer production: learn from HGCAL, statistics from current wafer batch ?

- Long SLAB: 1st readout over long chain: design R&D, power distribution, grounding; connexions between ASU’s
  - ⇒ adjustment on HV & LV distribution, clock distribution needed ⇒ realistic (mech. constraints) design in 2019 ?
Back-up
Slab plug

The slab plug is identical for both models.

On top of the TDD model an aluminium plate of 0.7mm has been added (simulation)

Example of realistic design (M.A.)
## Sketch for a Historical Picture of the Progress of the ILD Silicon ECAL

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Date</th>
<th>Object</th>
<th>Details</th>
<th>REM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1(^{st}) ASIC proto</td>
<td>2007</td>
<td>SK1 on FEV4</td>
<td>36 ch, 5 SCA</td>
<td>proto, lim @ 2000 mips</td>
</tr>
<tr>
<td>1(^{st}) ASIC</td>
<td>2009</td>
<td>SK2</td>
<td>64ch, 15 SCA</td>
<td>3000 mips</td>
</tr>
<tr>
<td>1(^{st}) prototype of a PCB</td>
<td>2010</td>
<td>FEV7</td>
<td>8 SK2</td>
<td></td>
</tr>
<tr>
<td>1(^{st}) working PCB</td>
<td>2011</td>
<td>FEV8</td>
<td>16 SK2 (1024 ch)</td>
<td></td>
</tr>
<tr>
<td>1(^{st}) working ASU in BT</td>
<td>2012</td>
<td>FEV8</td>
<td>4 SK2 readout (256ch)</td>
<td>best S/N ~ 14 (HG), no PP retriggers 50–75%</td>
</tr>
<tr>
<td>1(^{st}) run in PP</td>
<td>2013</td>
<td>FEV8-CIP</td>
<td></td>
<td>BGA, PP</td>
</tr>
<tr>
<td>1(^{st}) full ASU</td>
<td>2015</td>
<td>FEV10</td>
<td>4 units on test board</td>
<td>S/N ~ 17–18 (High Gain)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1024 channel</td>
<td>retrigger ~ 50%</td>
</tr>
<tr>
<td>1(^{st}) SLABs</td>
<td>2016</td>
<td>FEV10 &amp; 11</td>
<td>7 units</td>
<td></td>
</tr>
<tr>
<td>pre-calo</td>
<td>2017</td>
<td>FEV10 &amp; 11</td>
<td>7 units</td>
<td>S/N ~ 20, 6–8 % masked</td>
</tr>
<tr>
<td>1(^{st}) technological ECAL ?</td>
<td>2018</td>
<td>SLABvFEV10 &amp; 11 &amp;</td>
<td>SK2 &amp; SK2a ((\sim) timing)</td>
<td>Improved S/N Timing...</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13 SK2a+ COB +</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Compact stack</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Optimal cell-size (DBD)

*Detector optimisation studies (Cambridge/DESY):

Jet Energy Resolution / %

2.5 3 4 4.5

Pandora Preliminary

Steepest gradient

Flat-ish gradient

Jet Energy Resolution / %

45 GeV Jets
100 GeV Jets
180 GeV Jets
250 GeV Jets

ECal Cell Size / mm
0 5 10 15 20 25

HCal Cell Size / mm
0 50 100

45 GeV Jets
140 GeV Jets
180 GeV Jets
250 GeV Jets

*See optimisation studies slides for reconstruction details.