The CALICE AHCal: a high-granular SiPM-on-tile hadronic calorimeter prototype

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On behalf of the CALICE Collaboration

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Calorimeters for future colliders

- **CALICE**: development of *calorimeters* for future colliders.
  - Most likely one of ILC / CLIC / CEPC / FCC-ee.

- Target *hadronic calorimetry with a few % resolution*.
  - Not possible using calorimetry alone.
  - Extensive usage of *particle-flow algorithms*.
  - Requires *high granularity*.
  - → “Imaging” calorimeter: resolve jet-components.
Calorimeters for future colliders

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- **AHCal**: Analogue Hadronic Calorimeter
  - Plastic scintillator tiles.
  - SiPM readout.
  - Total 8M channels!

4m inner diameter and length
The Analogue Hadronic Calorimeter

- 1 board = 36x36 cm² (144 channels)
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- 1 channel =
  - 1 **SiPM** (Hamamatsu S13360-1325)
  - 1 **scintillator tile** (30 x 30 mm², 3 mm thick), polystyrene.
  - Individually wrapped in reflective foil, and glued on PCB.
A. Tile produced in Moscow, wrapped in Hamburg
B. SiPM tests in Heidelberg, mounted in DESY.
C. Tile gluing in Mainz.
D. Validation and calibration in cosmics test stand in Mainz.
+ many more institutes…

→ ~22'000 channels (dead channels < 1‰)
• **3 test-beams @ CERN** with different configurations:
  • **AHCAL standalone**: 38 layers (72x72 cm$^2$: 4 boards each) with 1.7 cm steel absorber = 4$\lambda$
  • **AHCAL + 8 layers of tail catcher** (CMS HGCal prototype) with 7.4 cm steel absorber.
  • **HGCal + AHCAL**.
• Since then, **many more TB @ DESY** with smaller & more dedicated setups.
Example result: sum of cell energy

Beam Tuning several energies

Electron beam

Pion Beam

CALICE work in progress

muons

10 GeV

20 GeV

30 GeV

40 GeV

50 GeV

10 GeV

40 GeV

60 GeV

100 GeV

CALICE work in progress
SiPM response is sensitive to temperature (gain & photon detection efficiency).

Can be stabilised by adapting the bias voltage.

“Temperature compensation” used all along data taking.

Gain stays stable!
Power-pulsing

- **Readout chip:**
  - Adapted to ILC beam structure: 1 ms spill every 200 ms.
  - Low consumption (< ~25 µW) using **power pulsing** (0.5% duty cycle).

- **Different results with and without power pulsing:**
  - Tracked down to different temperature compensation behaviour.
  - Corrected using dedicated calibrations for power-pulsing mode.

**Comparison with and without power pulsing**
- First look with online calibrations (the same for data with and without power pulsing): see a ~4% shift in energy sum!
- Effect in electron and pion data everywhere in the detector!
- Number of hits agrees e 80 GeV pions

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**CALICE work in progress**

- No PP
- PP

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**CALICE work in progress**

- No PP
- PP pions
Timing studies

- **Target resolution:** ~1 ns.
- **Dedicated test-beam @ DESY with 5 layers:**
  - Single channel resolution in ILC mode*: ~0.78 ns.
- Try to separate electronics from intrinsic SiPM-on-tile contributions: dedicated setup with different front-end electronics during test beam at DESY.
  - Measured **intrinsic resolution**: $0.714/\sqrt{2} = 0.507$ ns.
  - Deduced **front-end electronics contribution**: ~0.6 ns.

*: Test beam mode: 250 kHz clock (better suited for TB, but worse resolution)
*: “ILC mode”: 1 MHz clock
New hardware development:
KLauS ASIC
Megatile scintillators
KLauS ASIC: new readout chip

- Active development of new ASIC (Uni Heidelberg).
  - Version 6 currently under test.
  - Close to final design!
  - Target \(~1\, \text{ns time resolution}\), Power pulsing, low power
  - 2 gains,
  - …

- Same as SPIROCv2

- More versatile design than SPIROCv2.
  → Allows more flexible beam conditions.

- Same packaging as SPIROCv2.
  → Easy integration into AHCal board.

KLauS6 (5x5 mm²)
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Megatile concept

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Can we ease the construction?

• Build **one single** 36x36 cm² **tile**.
• **Cut trenches** and fill with **optical insulation**.
• Pour flowing **glue + TiO₂ mixture** → reflectivity.
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- Put large reflective foil sheet directly on board (with laser-cut holes for SiPM)
- Air gap (30-100 μm) to ensure total reflection.

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  - Same electronics boards.
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• **Easier assembly** 👍
• ~ **No dead area** 👍

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Light yield (LY) and cross-talk (XT) optimisation

- **Dimple shape:** already optimised for single tiles.
- **Trench angle:**
  - **Optimised for light yield** using simu.
  - Angle = 30°: minimal dead area.
- → **High light-yield ≈ as single tile**
- **Glue + TiO₂ dependency.**

![Diagram showing light yield and cross-talk optimisation](image)
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- Must be careful with air gap:
  - Too large → optical cross talk.
  - Simu: 3.5% for 100µm.

![Diagram of light yield and cross-talk optimisation](image)
Megatile: a promising concept

- **High light-yield** ≈ 32 p.e. / MIP
  ≈ as single wrapped tile 😊😊
- **Cross-talk**: ≈ 5%, OK (had. showers)

Here in cosmics bench @ Mainz, but already 3 test-beams @ DESY!
Megatile: a promising concept

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Still, comes with its own challenges:

- Air-gap control in test-beam.
- Ensure light-tightness of the edges:

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**Antoine Laudrain (JGU-Mainz)**

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**Glue+TiO2**

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**The CALICE AHCal**
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- Air-gap control in test-beam.
- Ensure light-tightness of the edges:
  - Using **adhesive reflective foil**, but not easy and limited improvement.

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Glue+TiO2
Reflective foil

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  - **Under test**: use varnish spray!

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**Edge channels**

- **Uniformity map**: for each quadrant, plot \( LY / \langle LY \text{ in 25 central channels} \rangle \).
- **Average ratio** of the 44 edge channels: \( 0.67 \rightarrow 0.84 \).
- Not yet perfect, but already a >15% improvement. More studies ongoing!
Cross-talk in cosmics and test-beam

**Cosmic test stand:**

*uniform and low (~7%)*

*: older prototype, slightly worse than 5.*
Cross-talk in cosmics and test-beam

Cosmic test stand:
uniform and low (~7%)

DESY test-beam
large variation, up to 15%

*: older prototype, slightly worse than 5%.
Cross-talk: air-gap control

- Tracked down to **bending foil in test-beam setup**.
- In cosmic test stand, a weighting plate is used to ensure everything is flat.
Cross-talk: air-gap control

- Tracked down to **bending foil in test-beam setup**.
- In cosmic test stand, a weighting plate is used to ensure everything is flat.
- Idea: **glue the foil directly to the megatile**.
- Tested in last test-beam, updated version for next one!
Conclusion

- Successful building and commissioning of the technological prototype with ~22’000 channels.
- Multiple very fruitful test-beam @ CERN-SPS in 2018, many ongoing analyses.
  - Very stable operation, thanks to temperature compensation.
  - Unexpected power-pulsing dependence observed and understood.
- Test-beams @ DESY with smaller setups for dedicated studies.
  - For example: timing resolution ~ 0.724 ns, better than 1 ns target!
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Construction of technological prototype was not easy.
• The Megatile is a promising concept to ease the assembly.
• High light-yield, but comes with its own challenges:
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  • Cross-talk is under control (< 5%)
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Stay tuned for more results!

Thanks for your attention!
BACKUP
SiPMs → SiPM sample tests
ASICs → ASIC tests → HBU soldering → LED tests → HBU tiling → Cosmic tests → Cassette assembly → e beam calibration → HCAL integration

Software data base analysis

Excellent opportunities for young scientists

Heidelberg
Wuppertal
Moskau
Palaiseau
MPP Munich
Wuppertal

SiPMs
ASICs
ASIC test board
PCBs
Tiles
Interfaces
Cassettes
Stack

HBU soldering
LED tests
HBU tiling
Cosmic tests
Reflector wrapping
Cassette assembly
Cooling

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