CALICE AHCAL overview

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Outline

- Overview

- Construction: AHCAL technological prototype

- Test beam activities
High granularity and SiPM: a brief history

• 2001: CALICE founded
  • Aim to develop high-granularity calorimeters at a future linear collider

• 2003: MiniCal (100 tiles+SiPMs)

• 2006-2011: AHCAL Physics Prototype
  • Test beam data at CERN and FNAL
  • Detailed shower studies

• 2012: CLIC studies triggered LHC interest
  • Particle-flow paradigm and pile-up rejection with high granularity in harsh conditions

• 2014-2017: CMS HGCAL design

• 2016-2018: AHCAL Technological Prototype for ILC
  • Demonstrate the scalability to build a full detector
AHCAL overview

- Sandwich calorimeter: scintillator-SiPMs with steel absorbers
  - Electronics fully integrated into active layers
- High granularity: 8M channels in total
- Challenges for mass assembly and data concentration
- Power-pulsing at ILC: passive cooling for active layers
AHCAL overview

• Passive cooling for AHCAL active layers at ILC
  • Power-pulsing at ILC: low duty cycle (1%) with bunch trains at 5 Hz
  • FE electronics designed for the ILC bunch structure

• Challenges for CEPC: no power pulsing
  • Electronics: continuous readout
  • Cooling scheme
High granularity: numbers!

- AHCAL
- 60 sub-modules
- 3000 layers
- 10,000 slabs
- 60,000 HBUs
- 200,000 ASICs
- 8,000,000 SiPMs + tiles

- 1 year
- 46 weeks
- 230 days
- 2,000 hours
- 120,000 minutes
- 7,200,000 seconds

Key: automated mass assembly
Evolution of the SiPM-tile design

2003: MiniCal

2005-2012: tile with WLS

2009-2014: tile without WLS, side-coupling

2013-2016: SiPM-on-tile, bottom coupling

A long way to the design for automated mass assembly
AHCAL tech. prototype: goals

• **Technology**
  - Demonstrate the scalability to build a final detector
  - Validate automated assembly and QA procedures
  - Evaluate the performance with
    - Active temperature compensation
    - Power pulsing

• **Physics**
  - Study showers in 5D
    - Energy, 3D position and timing (ns)
  - Validate simulation models in Geant4
  - Study timing in particle flow
Detector unit: SiPM-on-tile design

- SiPM: greatly improved performance
  - Reduced dark count
  - Lower inter-pixel crosstalk
    - Noise rate decreases quickly with threshold
  - Good uniformity (operational voltage, gain)
    - Simplifies in-situ calibration

- Tile design
  - Simple for tile mass production (by injection molding)
  - Excellent response uniformity
  - Suitable for automated mass assembly with surface-mounted SiPMs
Construction and QA

Scintillator tiles by injection molding

Wrapping machine

ASIC test stand

SiPM test stand with laser

Readout modules

Automated assembly machine

On-board LED testing

Cosmic test stand
Tile wrapping

- Scintillator tiles need wrapping with reflective foil for optimal performance
- A custom-made machine for wrapping

Started in Oct. 2017

25k tiles in total
Tile assembly

- Glue dispensing machine: put glue on PCB before tile assembly (not in photos)
- Pick-and-place machine (industry standard): trained for tile assembly

Started in Nov. 2017
Quality Assurance (1)

• Scintillator tiles
  • Spot check for mechanical tolerances
  • Some deviations affected automated wrapping and assembly

• SiPMs:
  • Spot check for break-down voltage, gain, noise, cross-talk
  • All samples passed, excellent uniformity

• ASICs
  • Semi-automated tests on a dedicated board
  • Yield 80~90%
Quality Assurance (2)

• Readout modules (HBUs) without tiles
  • Tested with on-board LEDs system before tile assembly
  • 158 out of 160 boards OK

• HBUs with tiles
  • Extensive tests with cosmic muons
  • Most boards: very good light yield uniformity
Active layer: integration and commissioning

- Interface boards
  - A set can serve up to 18 readout modules for the ILC HCAL
  - DIF: interface between ASICs and data concentrator
  - CALIB: control on-board LEDs
  - POWER
    - Power distribution and regulation
    - Cycling capacitors for power pulsing

An active layer: 2x2 HBUs with a set of interface boards
Active layer: commissioning

• Commissioning with cosmic muons:
  • Light yield
  • DAQ stability

• Commissioning with DESY electron beam
  • 5 layers at a time without absorbers (in “air stack”)
  • Initial MIP calibration: automatic scan for all channels
  • Active temperature compensation for SiPMs

• 8 dead channels out of 21,888 in total
Stack integration and commissioning

- Integration
  - Stack: dimensions for a module of the final full collider detector
  - Data concentration
    - Wing-LDA (hardware)
    - 1x Ethernet for data from all layers
  - Data acquisition: EUDAQ
  - Cooling system
    - Only for interface boards

- Commissioning with cosmics
  - Test the full software chain
AHCAL technological prototype

- 38 active layers
  - 21,888 channels
  - 608 ASIC chips
  - 2x2 HBUs (72x72 cm²) per layer
    - 576 channels

- Absorber structure
  - 40 layers (EUDET stack)
  - 1.7cm thick per layer
  - ~4\(\lambda\) in total
Goals of SPS beam tests

- **Technology**
  - Demonstrate capabilities of the SiPM-on-tile calorimeter concept with a scalable detector design
  - Achieve reliable operation of a large prototype

- **Physics**
  - SiPM-on-tile HCAL performance: energy linearity and resolution up to 100 GeV
    - For single particles: electrons, pions
  - Shower profiles and separation
  - Shower timing
Beam tests at CERN SPS in 2018

• 2 beam periods at SPS H2
  • 2 weeks in May 2018
  • ~1 week in June-July 2018

• Setups
  • In May: AHCAL main stack
  • In June: as in May, plus
    • One module with 6x6 cm² tiles
    • Tail-catcher, CMS HGCAL “thick stack” (12 layers of single HBU, 7.4 cm thick steel absorber)
    • Single HBU in front of absorber as pre-shower
  • Mounted on the movable platform

• Beam area instrumentation
  • Wire chambers
  • Trigger scintillator
  • Cherenkov counter
Data taking status

• General
  • Stable running
  • All layers working well, <0.1% dead channels
• Muons: MIP calibration
  • Scanning at several positions
• Electron: energy scan
  • Range: 10-100 GeV
  • 0.2~0.4 M events per energy point
  • With and without power pulsing
• Pion (negative): energy scan
  • Range: 10-200 GeV
  • 0.4~0.6 M events per energy point
  • With and without power pulsing
Gain calibration

- Extracted from on-board LED data
- Pedestal
  - Hints on noisy/dead channels
- SiPM gain
  - ADC translated to #pe in SiPM
  - Basis for SiPM saturation calibration
  - Monitoring SiPM/detector stability
- Status
  - Homogeneous gain
  - Stable operation

Pedestal

RMS: ~6%

SiPM gain
Inter-calibration: high gain and low gain

• 2 modes: High gain vs low gain
  • Two preamps in ASIC with different amplification factors
  • To increase the dynamic range
  • The ratio of two amplification factors: inter-calibration
  • Extracted from LED data

• Next steps
  • Pedestals in low gain mode
  • Application to testbeam data
MIP calibration

• Muons: position scan of the full detector
  • Use pedestals from non-triggered channels (~350k constants!)
  • Determine MIP scale for all channels (~22k channels)

• Calibrations for May and June data: done
  • Without and with power pulsing

Raw amplitude spectrum

Calibrated amplitude spectrum

New: MPV = 0.99995834
First glance at testbeam data

Electrons during beam tuning in June

CALICE work in progress

Electrons

Pions

Energy Sum
Entries: 74822
Mean: 866.6
RMS: 462.7

Beam Tuning several energies

Pion Beam

10 GeV

40 GeV

60 GeV

100 GeV

Energy [MeV]

Energy Sum [MeV]
Common CALICE-CMS beam test

- CERN SPS H2: 2 weeks in Oct 2018
  - 94 silicon modules (6") in the ECAL and front HCAL section (up to 40 layers)
  - 156 SiPM-on-Tile modules (39 layers) in the HCAL back section
    - =CALICE AHCAL prototype
  - Common DAQ: EUDAQ2 (AIDA2020)
Further R&D: new SiPM and ASIC

- New SiPM developed at NDL (Beijing Normal University)
  - High PDE with high pixel density (>=10k pixels per mm²)
    - Vertical quenching resistor: high fill factor -> high PDE
  - High dynamic range: mitigate non-linearity effect with strong signals
  - Promising candidate to measure EM showers

- KLauS ASIC (KIP, University of Heidelberg)
  - Low noise, low power dissipation
  - High precision for low-gain SiPM (small pixel size, e.g. ~10µm)
  - Continuous readout without dead time
Further R&D: SiPM studies with Klaus

- **Crosstalk:** 3.09% (OV=5V)
  - J. Jiang (IHEP)
  - Work in progress

- **Low crosstalk (a few percent level) can ensure fast noise drop with threshold**

- **Auto-trigger**
  - KIP, Uni-HD
  - Work in progress

- **External trigger**
  - KIP, Uni-HD
  - Work in progress

- **NDL-SiPM (1x1mm²) tested at IHEP**

- **NDL-SiPM tested with Klaus at KIP, Uni-HD**

  - Single photons can be well distinguished (for small SiPM gain (on the order of $10^5$))
Summary

• CALICE AHCAL technological prototype successfully built and commissioned
  • ~22,000 channels (156 readout modules)

• Demonstrated scalability to build a full detector
  • Novel detector design: SiPM-on-tile
  • Procedures for construction and quality assurance

• First beam tests with the AHCAL new prototype
  • Smooth and successful data taking
  • Calibrations finished
  • More analysis efforts ongoing

• Further R&D efforts
  • SiPM and ASIC, mega-tile, ...

• Plans: more beam tests (fast timing, tungsten absorber, ...)