Results from the first tile-HCAL prototype

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for the CALICE collaboration

- Tile-HCAL prototype: structure and readout
  - tile-fiber system optimization
  - used photo-detectors: PM, SiPM, APD

- MIP calibration:
  - stability
  - tile homogeneity

- MC studies
- Linearity and Energy Resolution
- Conclusion and Outlook

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Goal of MiniCal

First working prototype to test the concept of high granularity tile-calorimeter:
- light yield optimization
- tile uniformity
- test of novel photo-detector
- MIP calibration
- stability monitoring
- MC simulation

MiniCal prototype has been operational since May 2003 at the DESY test beam: 1 - 6 GeV e

It is a collaborative effort of various institutes:
HH-university, DESY, MEPHI, Prague, LPI, ITEP

Get ready for studies on Physics Prototype ...

→ see M. Danilov talk
The MiniCal Prototype

e^+ 1-6 GeV

97% shower contained in 11 layers

0.1 cm Ø WLF cassette
0.5 cm active
2 cm steel
The Cassette Structure

Tile size: 5x5x0.5 cm³
Tile material: Bicron BC408, Protvino, Vladimir

**Conventional coupling**

1-loop or curve-diagonal WLS-fiber (Y11) placed in groove (not glued)
Single tiles covered by 3M reflector

**Direct coupling**

higher light yield

1 cell = 3 tiles combined in depth (for PM/APD)
Test of 3 types of Photo-Detector

**MA-PM** - 16 channels (Hamamatsu):
- best photo-detector
- cannot be operated in magnetic field
- single tile or cell read out

Only for reference

**Silicon photo-multiplier (SiPM):**
- new detector concept, first test with beam
- sizes: 1x1mm², 1024 pixels/mm²
- gain ~ $1 \times 10^6$ → No preamplifier needed
- quantum eff. ~ 15-20%
- single tile read out / mounted directly on tile

**Avalanche photo-diode (APD, Hamamatsu S8664-55spl):**
- different from those used by CERN experiments
- 3x3mm² low capacity
- gain ~ 200 → various preamp board tested @ DESY
- quantum eff. ~ 75%
- cell read out: 3 tiles

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MIP Calibration

- Obtained using 3 GeV electron beam on single tile, w/o absorber in front

PM:
- $\text{MIP}/\sigma_{\text{ped}} \approx 15$
- $\text{MIP}/\sigma_{\text{MIP}} \approx 4.5$

SiPM:
- $\text{MIP}/\sigma_{\text{ped}} \approx 30$
- $\text{MIP}/\sigma_{\text{MIP}} \approx 3.7$

APD:
- $\text{MIP}/\sigma_{\text{ped}} \approx 10$
- $\text{MIP}/\sigma_{\text{MIP}} \approx 4.0$

$\text{MIP} := \text{MPV-pedestal}$
Tile Calibration Scan

9 point scan of the tile centre according to:

\[ \pm 2\% \text{ possible calibration uncertainty due to tile inhomogeneity} \]
Slow Control Monitor

Daily monitor of MIP calibration versus:
- temperature fluctuations
- High Voltage stability

(example for PM monitoring)

- 2% calibration reproducibility
- good HV stability
- 1-2 °C temperature variation crucial for APD monitoring

⇒ see J. Cvach talk
SiPM Calibration

- MIP calibration with beam of all tiles w/o pre-amplifier
- Single pixel peak visible with fast pre-amplifier ➔ for calibration only

One pixel peak  MIP peak

With low intensity LED

Without LED light 1 pixel noise visible

RESULTS FOR THE TILE 231:
Ped pos = 79.54 ch.

\[ \Delta = 10.22 \text{ ch/cell} \]

MIP Amplit. = 254.55 ch/MIP

N phe = 24.91 phe

1 MIP = 25 pixels
SiPM response function

Response curve measured with LED pulse shape similar to tile response to MIP (~ 15 ns FWHM)

1. 1024 pixel SiPM saturates at ~ 2000 effective pixels:
   - very short recovery time ~ 10 ns
   - each pixel can fire twice during the duration of the tile+WLS fiber signal
SiPM Calibration

- N Pixels/MIP extracted for >100 SiPM
- 1 MIP = 25 ± 4 pixels
- the average number can be used to calibrate all SiPM

![Graph showing SiPM calibration results.](image)

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Reproducibility

- energy scan with different beam positions
  - vary energy shearing between tiles
  - different saturation correction
- results in very good agreement
  - Saturation correction well under control
SiPM Stability

- Voltage variation applied
- Corrected by temperature dependence correction

Temperature and voltage dependence:
variation of $-14 \, ^\circ C \approx +0.3 \, V$
- +6 % gain and photo-detection eff.
MC simulation of MIP

- detector description implemented in GEANT4
- MC has to be smeared according to detector properties

- single tile MC calibration needed:
  - # ph.e/MIP
  - width of 1st photo electron peak

- good description of MIP shape after MC calibration

→ MC tune for PM
Shower Shape

After single tile calibration and smearing

MC well describe PM shower shape

Layer 1

Layer 3

Layer 5

Layer 7

Layer 9

Layer 11

3 GeV e⁺
Applying 5% smearing on calibration factors the high energy data are well describes.

At low energy MC 6% lower than data.

Ideal MC includes only MiniCal geometry description.

After single tile calibration MC resolution is decreased but still does not match the data.
Results comparison: N MIP

Sum of total energy deposited in calorimeter calibrated in number of MIPs

- Very good agreement between SiPM and PM
- MC tuned to SiPM properties gives good description of the data
Energy Resolution

- **Very good agreement between PM and SiPM on the whole range 1 - 6 GeV**

- **Low sensitivity to constant term due to limited energy range**

- **MC tuning still in progress**
  - include more effects:
    - beam energy spread
    - steals thickness tolerances
Monitoring System

Next studies will focus on a reliable monitoring system for large number of tiles (>8000 for the physics prototype)

Requirements:
- low light yield (~ 5-10 ph.e.) pre-amplification is required ➔ to monitor SiPM gain
- medium light yield (~ 25 ph.e ~ 1 MIP) ➔ to monitor stability of MIP calibration
- high light yield (~ 200-500 ph.e.) ➔ to monitor saturation behaviour

Options under investigation:
- LED system, single or multiple tile per fiber
- Laser system
Conclusion & Outlook

- Beam tests with MiniCal at DESY have been rather successful 😊
  - Optimized light yield in tile readout
  - Studied different readout systems (PM, SiPM, APD presently undergoing)
  - Established reliable calibration system
  - Checked long term stability
  - Established detailed MC simulation still to be finalized
  - Developed stability monitoring system see J. Cvach talk
  - Gained lots of experience for constructing physics prototype

- In 2005 move to hadron beam to fully test HCAL performance