Calorimeter test-beam results with APDs

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- Test set-up, APD, preamplifiers
- Calibration
- Results
- Future options with APDs
Analog HCAL – MiniCal

- Test calorimeter – MiniCal
  20x20x80 cm³ with tiles 5x5x0.5 cm³
  SS absorber – 2 cm thick
- 3.1 $\lambda$, 30 $X_0$
- Photodectors in tests:
  - MAPM – a reference
  - SiPM – DESY 04-143
  - APD – this talk – soon published
- Calibration and monitoring
- DESY $e^+$ beam 1-6 GeV
- Decision taken how to build ppt
Beam tests setup

12 planes
32 APD channels

Cassette – 1 plane
• 9 tiles 5x5x0.5 cm³ (Bicron BC408)
• WLS (Kuraray Y11-300)
• Covered by 3M reflector
APDs

- We use Hamamatsu single channel APDs S8664-55 (3x3 mm²)
- High quantum $\varepsilon \sim 80\%$, gain $M > 100$
  ($\Delta U/U \sim 10^{-4}$ for 1% gain stability)
  → Low noise preamps and stable power supplies
- APDs grouped according to gain
- Gain - temperature sensitive
  $1/M \frac{dM}{dT} \sim -4.5\%/\text{deg}$

- 2 types of preamps (9 channels/ PCB):
  - Prague: voltage preamp – discrete components
  - Minsk charge preamplifier – 1 integrated channel (CMS type)
Comparison of preamplifiers

Prague preamplifier
- Voltage sensitive
- Peak sensing + shaping
- Rise time ~ 40 ns
- Fall time ~ 180 ns
- Supply voltage 10-12 V

Minsk preamplifier
- Charge sensitive
- Charge integration + shaping
- Rise time ~ 70 ns
- Fall time ~ 350 ns
- Supply voltage 5 V

- Minsk better in S/N ≈ 9, size and power consumption
- Prague better in dynamic range, linearity and xtalk

Nevertheless, difference in preamps not seen in results!
Fit in every channel
- Gaussian for pedestal
- Gaussian (and Landau distribution - sampling fluctuations) for positron

MIP = (positron – pedestal) peaks
renormalization constant for each channel

Energy(MIPs) = \( \Sigma \) over channels
APD monitoring by LED

- LED light – 10 Hz to all APDs
- LED monitored by PIN diode
- APDs stable within ~ 1% over period 5 hours, typical run period
- Temperature variations:
  < 1.0° C over period of 84 hours
- APD amplitude has a mirror behaviour wrt the temperature variations – OK
- It is very well reproduced by the temperature dependence of the APD gain
- APD/PIN monitoring of LED light → offline correction
Longitudinal shower shape: data and MC

- For comparison with PM & SiPM
  12 layers in core read individually
- no. of APDs limited – only 32 available!
- for outer cells 3 tiles combined to 1 APD

- Longitudinal profile of 5 GeV $e^+$ beam in the central tile
- Most energy deposited in layers 3 – 5
- Good description by MC

Not read
3 tiles/APD
1 tile/APD

LCWS05, March 20, 2005
J. Cvach, Calorimeter with APDs
Lateral shower shape in data and MC

- 5 GeV $e^+$ beam in the centre tile – energy profile in the 5th layer
- GEANT4 with MiniCal geometry
- Simulation of the signal chain: $E_{\text{dep}}^{\text{tile}} \rightarrow N_{\text{pe}}$ & Poisson statistics & photodector efficiency $\rightarrow$ ADC
- MC parameters optimised to reproduce MIP shape for each tile
- >90% of energy in the centre
- Good agreement of MC and data
Systematic errors

- LED light $\rightarrow$ 8 APDs + PIN
- Off-line correction for power supply, temperature, … fluctuations
- Calibration + energy scan $\sim$ 5 hours
- PIN correction $\rightarrow$ stability on a % level
- Systematic error from time stability $\sim$3%
- Other sources of systematic errors(%):
  (relative error of signal $\uparrow$ with $E_{beam}$)
  - Different calibration methods 1
  - Electronics noise (pedestal) 6-1
  - Signal thresholds and cuts 2-1
  - ($E_{beam}$ $\pm$3%) $\rightarrow$ 1.5% in stochastic term

Statistical (1.0-1.5%) and systematic errors added in quadrature for each point
**Linearity**

- Signal summed ($N_{\text{MIP}}$) over 12 layers at each beam $E$
- Gaussian fit to get the most probable signal value $N_{\text{MIP}}$ and $\sigma$ at each $E_{\text{beam}}$
- Good agreement between two preamplifiers within 1-2 $\sigma$
  – not clear at the beginning; charge sensitive (Minsk) preamp has lower noise
- Good agreement with MC
- Good agreement with PM and SiPM:
  37.6 and 38.3 MIP/GeV

### Negative intercept (under investigation):
approaching 0 with $E_{\text{beam}}$↑

### Data Table

<table>
<thead>
<tr>
<th></th>
<th>$N_0$ (Prague)</th>
<th>$N_0$ (Minsk)</th>
<th>$N_0$ (MC)</th>
<th>$N_{\text{MIP}}$ (Prague)</th>
<th>$N_{\text{MIP}}$ (Minsk)</th>
<th>$N_{\text{MIP}}$ (MC)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$-4.3 \pm 1.8$</td>
<td>$-3.0 \pm 1.8$</td>
<td>$-3.3 \pm 0.0$</td>
<td>$37.4 \pm 0.7$</td>
<td>$36.0 \pm 0.7$</td>
<td>$36.7 \pm 0.0$</td>
</tr>
</tbody>
</table>
Linearity

- Intercept = -(3.6 ± 1.6) MIP
  \( E_{\text{beam}} = 1 – 6 \ \text{GeV} \)
  -(1.8 ± 1.8) MIP
  \( E_{\text{beam}} = 3 – 6 \ \text{GeV} \)
- \( \neq 0 \) due to low energies
- measured ADC nonlinearity at small signals (4 -1 %) leads to an opposite effect

- Gain increase by 1.6
  \( U_{\text{bias}} = 429 \rightarrow 434 \ \text{V} \)
  intercept = -(1.5 ± 1.6) MIP
- Negative intercept is not a problem!
Energy resolution

\[ \frac{\sigma}{E} (\%) = \frac{A}{\sqrt{E \text{ (GeV)}}} \oplus B \]

- Data with both preamps are consistent
- Stochastic term for all photodectors is \( A \sim 21\% \)
- MC stochastic term better by 3-4\% with respect to data
- APD measurements not sensitive to the constant term
- Constant term for SiPM \( B \neq 0 \) by \( 2\sigma \) - confirmed by MC
Future option with APD

- Particle flow concept:
  - Small tiles: 3x3 cm$^2$
  - Individual tile readout
- APDs inside a tile – as SiPMs
- Significantly lower gain can be compensated by:
  - High quantum efficiency
  - Low noise preamplifier close to APD
- Goals for the APD version of a future detector:
  - Large size APDs (25-100 mm$^2$) and low bias voltage
  - Direct tile readout without WLS fibre
  - Better scintillator – longer attenuation length (>2m)
  - Super-reflector foil with high blue reflectivity
- Final choice of photodector driven the combined cost of light read-out, photodector (+ integrated preamp), electric signal read-out
Future option with APD

- APD chips from Silicon Sensor
  AD 1100-8, Ø 1.1 mm, $U_{\text{bias}} \sim 160$ V
- Chip on PCB with a close preamp

- Comparison of new and old APDs

This APD meets some of future requirements
Conclusions

- Successful tests of analog HCAL – MiniCal in the DESY $e^+$ beam
- Photodectors tested – MAPM, SiPM, APD – give similar results:
  - linear response
  - energy resolution
- APDs were used at room temperatures
- APD have sufficient dynamic range – no saturation effects
- LED calibration system provides corrections for temperature and high voltage changes – it will be used in the physics prototype
- Thanks to all members of HCAL CALICE coll., especially those who contributed to these results: E. Devitsin, G. Eigen, E. Garutti, M. Groll, M. Janata, V. Korbel, H. Meyer, I. Polák, S. Reiche, F. Sefkow, J. Zálešák
MC simulation of MIP

- Calibrate MC by adjusting each channel to MIP signal

- Good description of MIP shape after MC calibration

from M. Groll
Modification of Calibration Procedure

- We used to fit the entire energy spectrum without any cuts to pedestal gaussian plus MIP gaussian and Landau tail.

- Now we require a MIP-like signal in layer 12 and fit resulting energy spectrum to a gaussian plus a Landau tail.

- The pedestal position is obtained from separate trigger now.

From G. Eigen
Photocathode homogeneity

12 APD tested
\rightarrow \text{homogeneity 6%}
\rightarrow 1 \text{ APD used to read out 3-4 tiles}