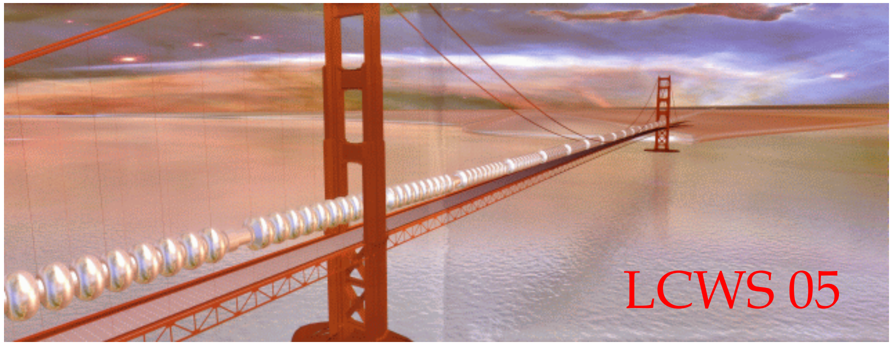


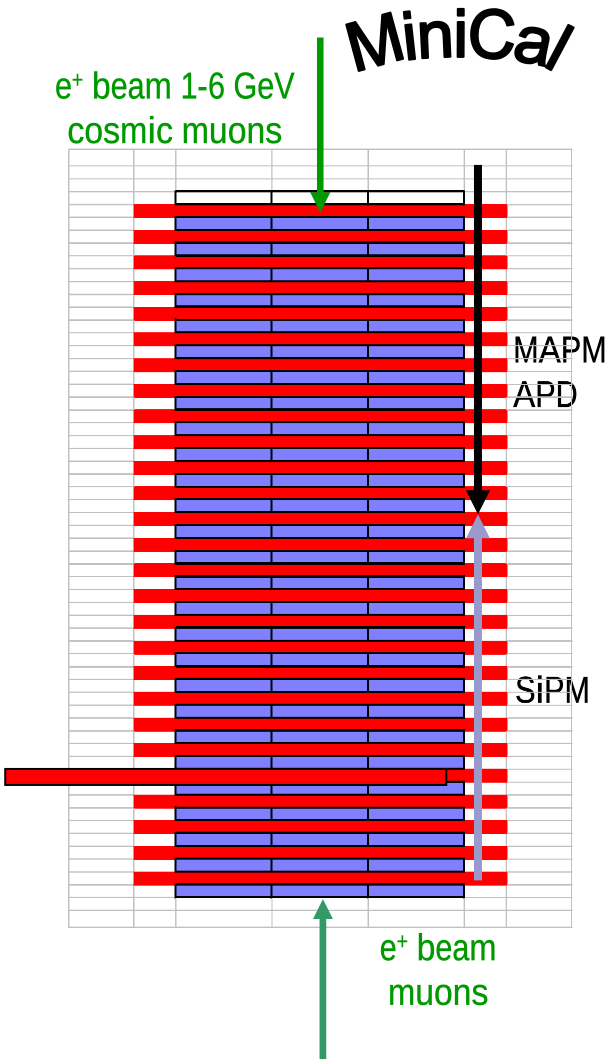
Calorimeter test-beam results with APDs

J.Cvach
Institute of Physics AS CR, Prague

- Test set-up, APD, preamplifiers
- Calibration
- Results
- Future options with APDs

Analog HCAL – MiniCal

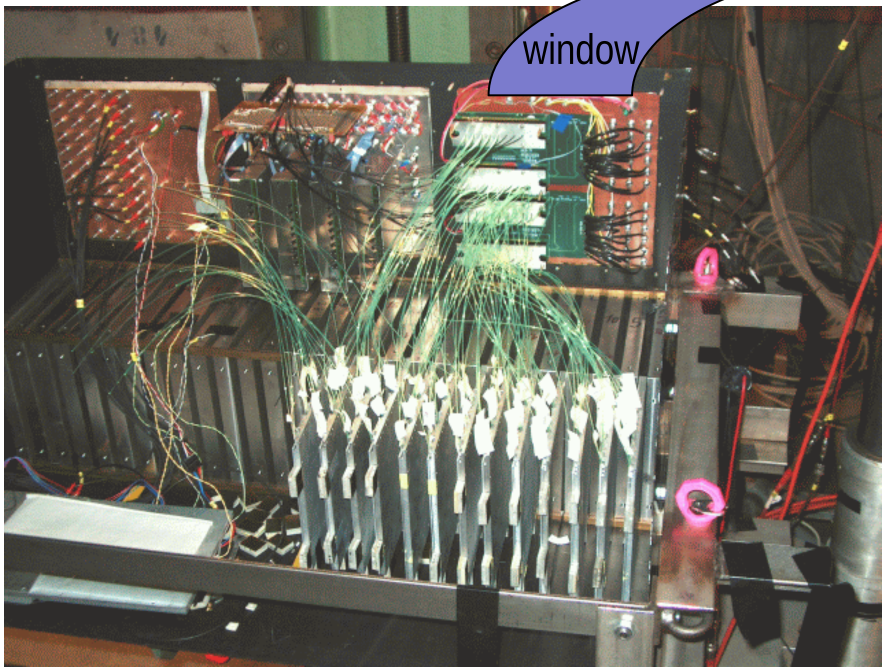
- test calorimeter – MiniCal
  20x20x80 cm^3 with tiles 5x5x0.5 cm^3
  SS absorber – 2 cm thick
- 3.1 λ, 30 X_0
- Photodectors in tests:
  - MAPM – a reference
  - SiPM – DESY 04-143
  - APD – this talk – soon published
- Calibration and monitoring
- DESY e^+ beam 1-6 GeV
- Decision taken how to build ppt



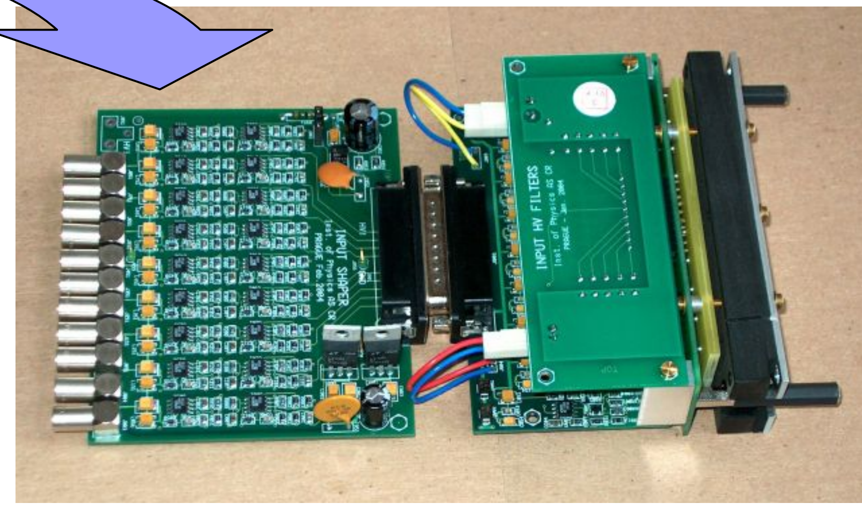
Beam tests setup

12 planes
32 APD channels

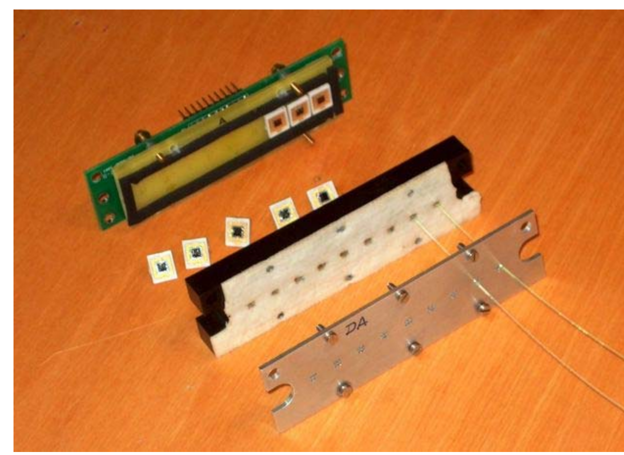
mask with APDs
preamps, shapers

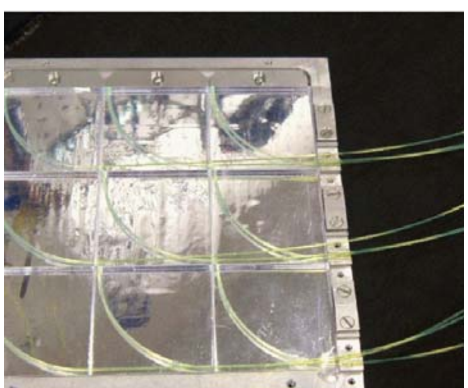


window



mask





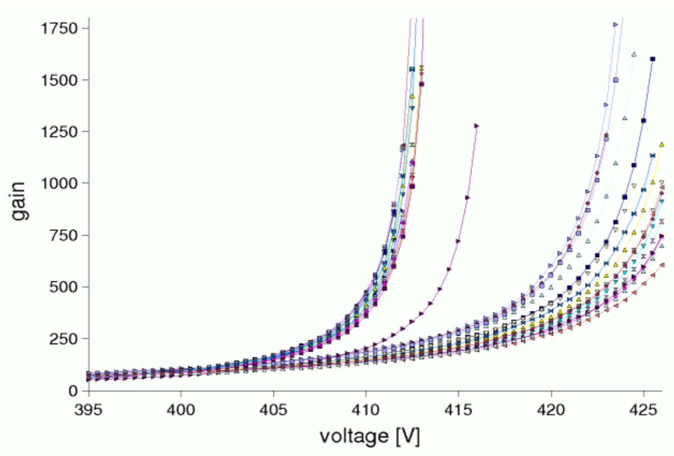
Cassette – 1 plane

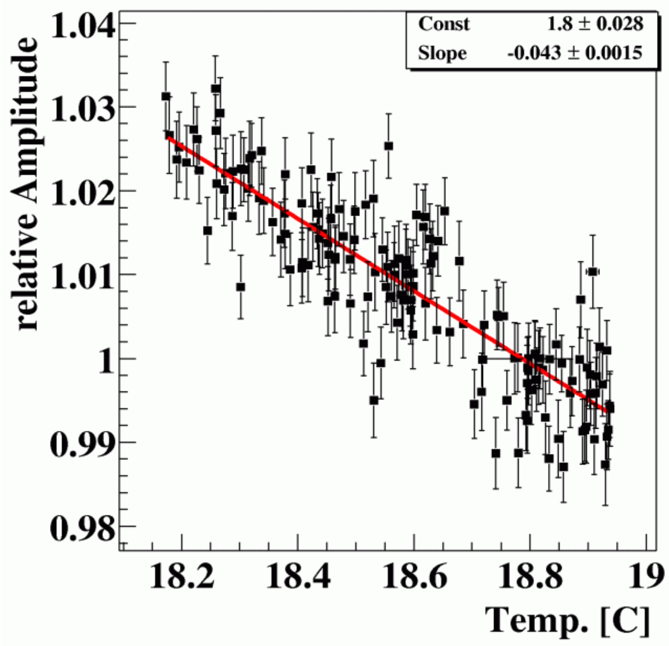
- 9 tiles 5x5x0.5 cm^3 (Bicron BC408)
- WLS (Kuraray Y11-300)
- Covered by 3M reflector

APDs

- We use Hamamatsu
  single channel APDs S8664-55 (3x3 mm^2)
- High quantum ε~80%, gain M > 100
  (ΔU/U ~ 10^{-4} for 1% gain stability)
  → Low noise preamps and stable power supplies
  APDs grouped according to gain
- Gain - temperature sensitive
  1/M dM/dT ~ -4.5%/deg

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





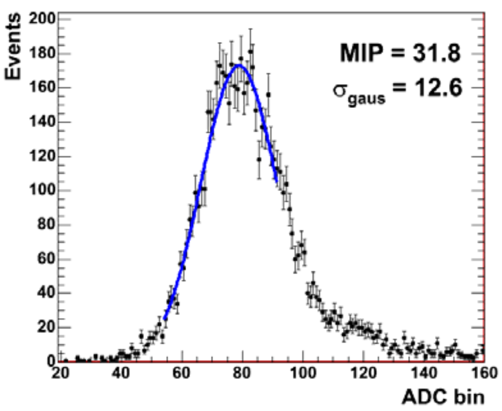
Comparison of preamplifiers

Prague preamplifier

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

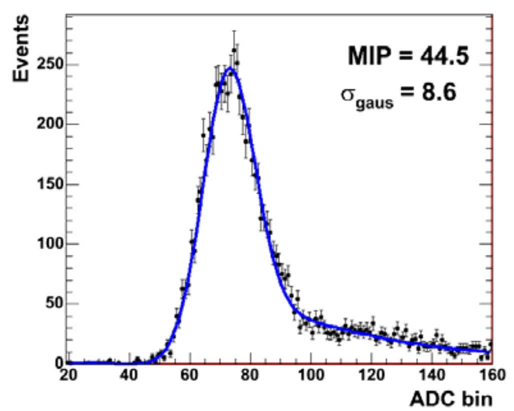
Minsk preamplifier

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

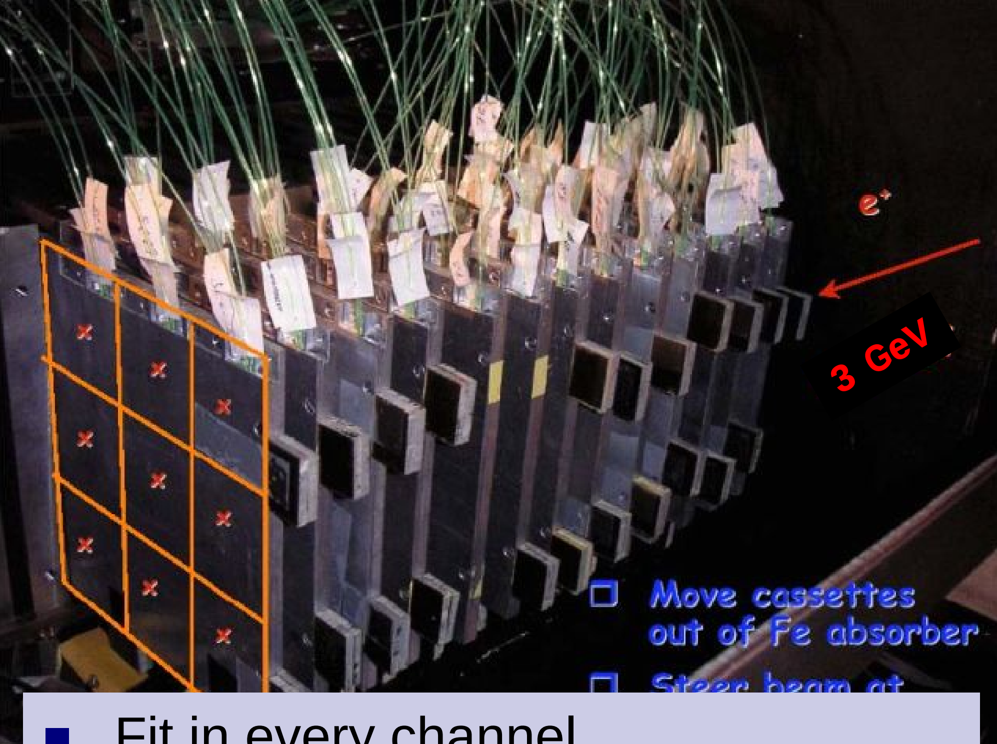


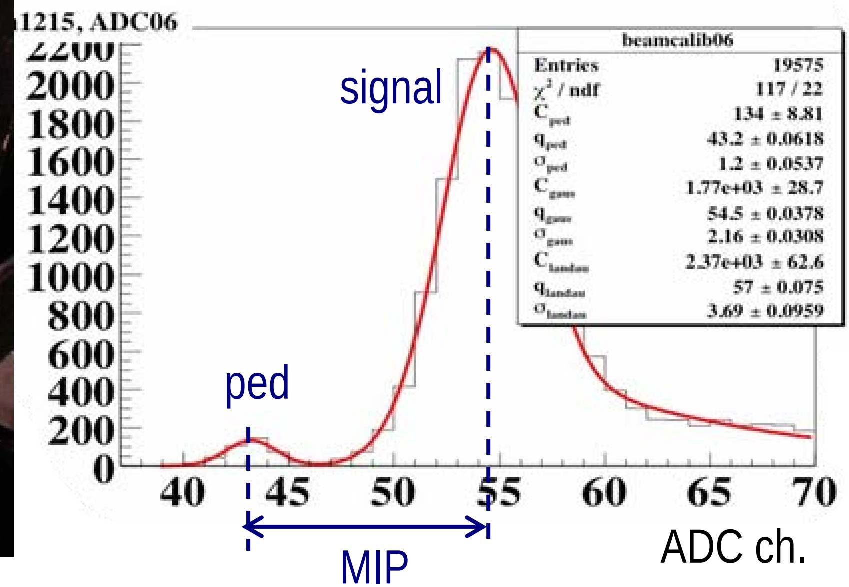
- Minsk better in S/N ≈ 9, size and power consumption
- Prague better in dynamic range, linearity and xtalk

Nevertheless, difference in preamps not seen in results!



Energy calibration

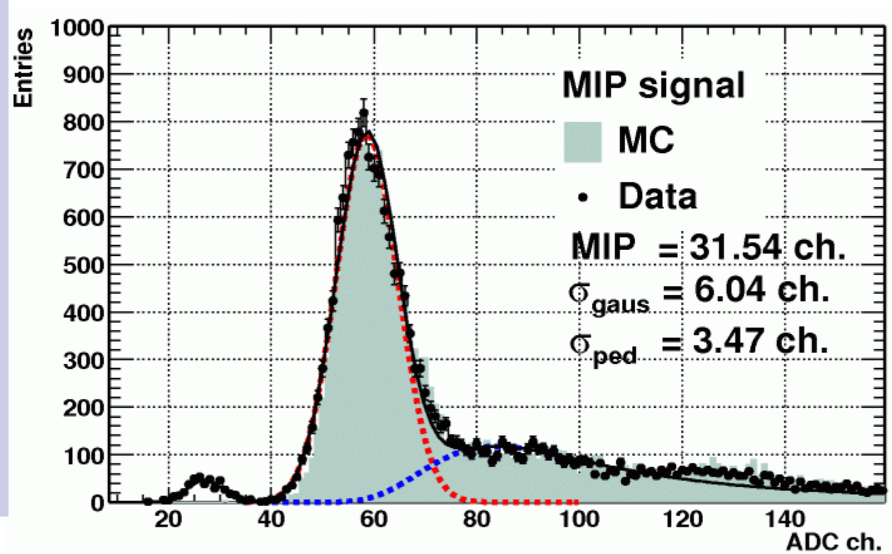




- Fit in every channel
  - Gaussian for pedestal
  - Gaussian (& Landau distribution - sampling fluctuations) for positron
- MIP = (positron – pedestal) peaks

renormalization constant for each channel

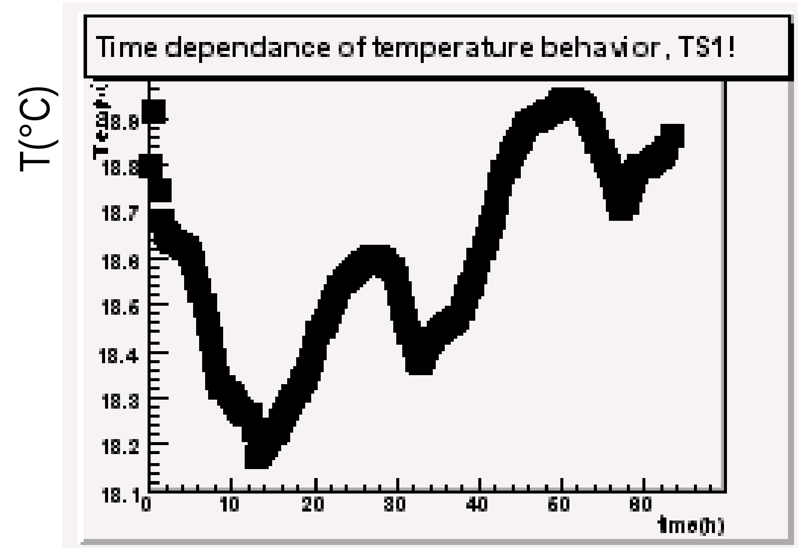
- Energy(MIPs) = Σ over channels

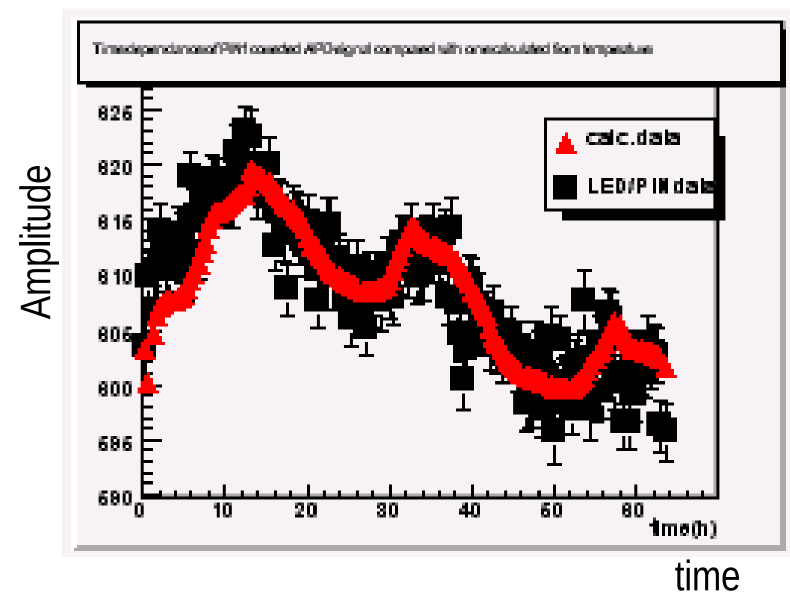


APD monitoring by LED

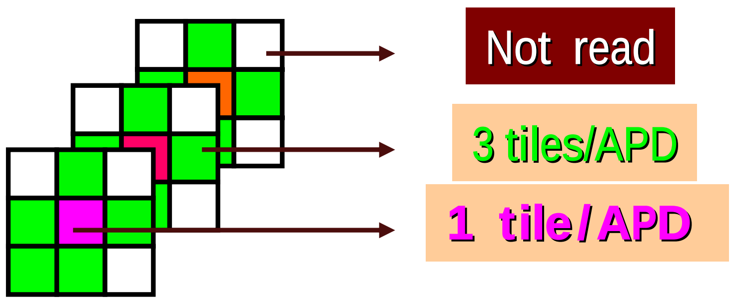
- LED light – 10 Hz to all APDs
- LED monitored by PIN diode
- **APDs stable within ~ 1%** over period 5 hours, typical run period
- Temperature variations:

  < 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

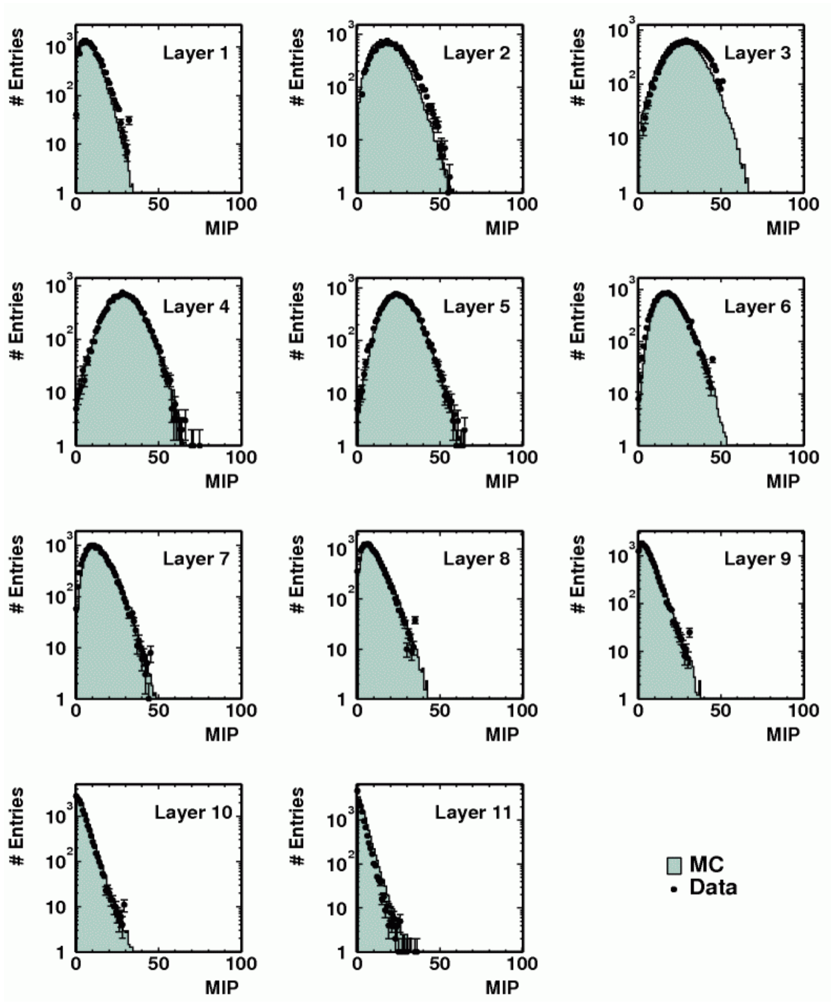




Longitudinal shower shape: data and MC



- 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

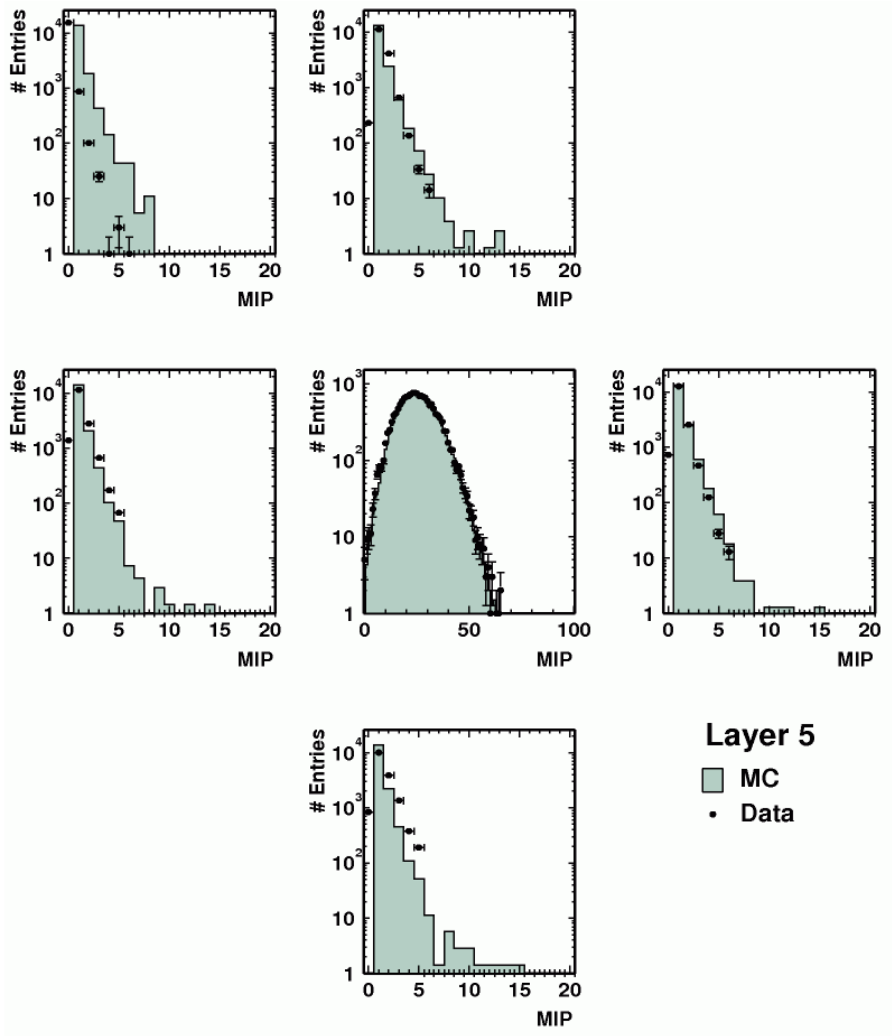


- Longitudinal profile of 5 GeV e^+ beam in the central tile
- Most energy deposited in layers 3 – 5
- Good description by MC

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:

  $E_{dep}^{tile} \rightarrow N_{pe}$ & 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

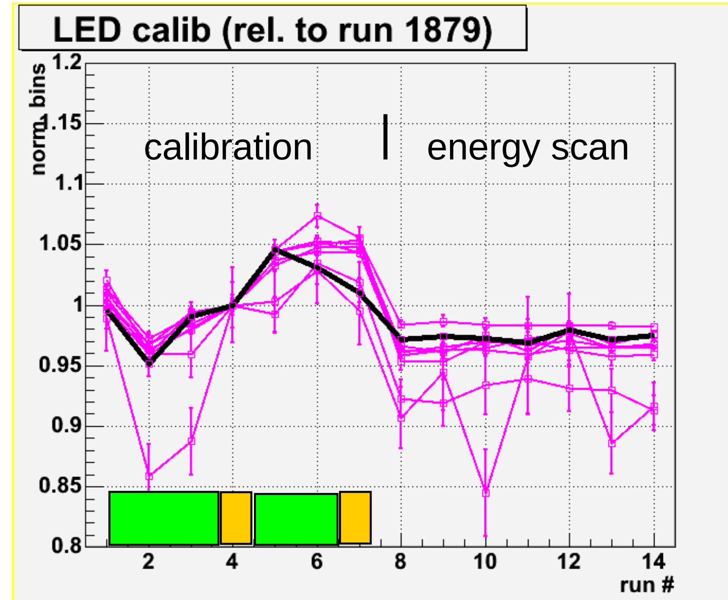
calibration run no.

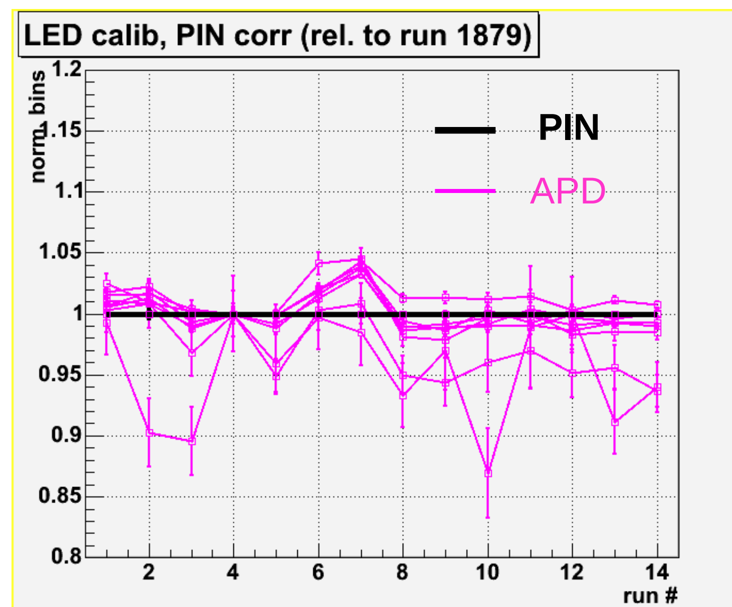
	6	
3	4,7	5
1	2	

- LED light → 8 APDs + PIN
- Off-line correction for power supply, temperature, … fluctuations
- Calibration + energy scan ~ 5 hours
- PIN correction → stability on a % level
- Systematic error from time stability ~3%
- Other sources of systematic errors(%):

  (relative error of signal ↑ with E_{beam})
  - Different calibration methods 1
  - Electronics noise (pedestal) 6-1
  - Signal thresholds and cuts 2-1
  - (E_{beam} (±3%) → 1.5% in stochastic term)

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



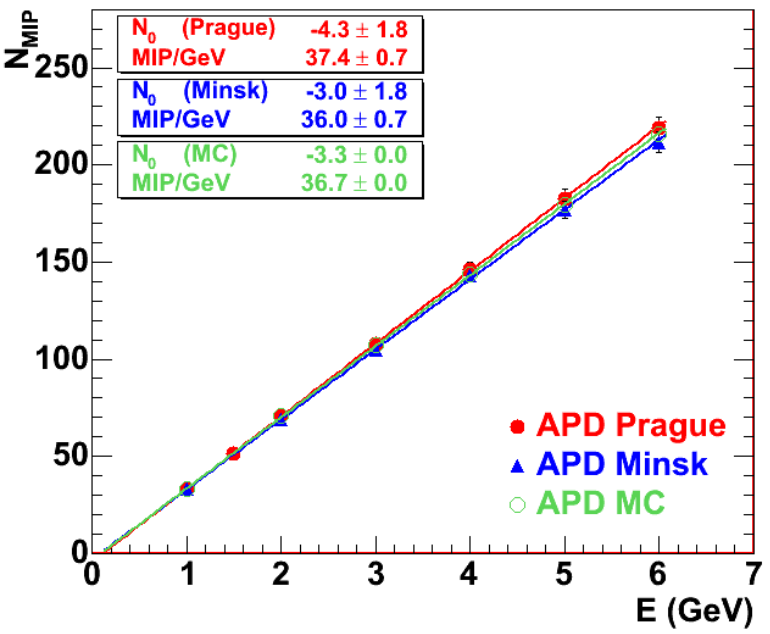


Linearity

- Signal summed (N_{MIP}) over 12 layers at each beam E
- Gaussian fit to get the most probable signal value N_{MIP} and σ at each E_{beam}
- Good agreement between two preamplifiers within 1-2 σ

  – 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 $E_{beam} \uparrow$

Linearity

- Intercept = -(3.6 ± 1.6) MIP

  E_{beam} = 1 – 6 GeV

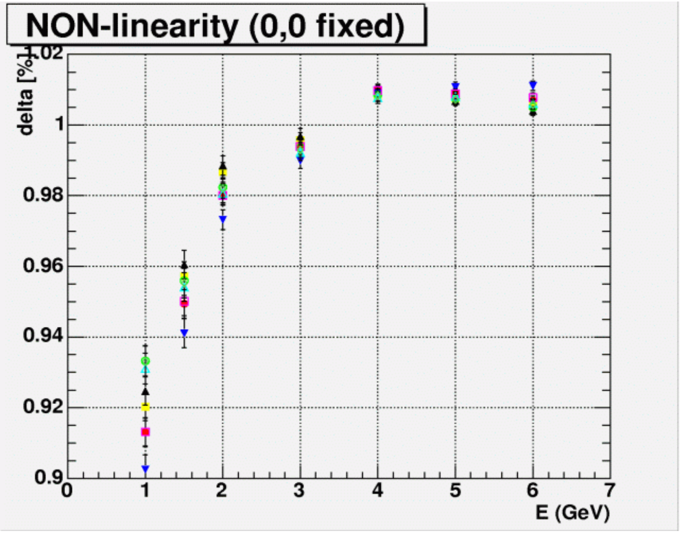
  -(1.8 ± 1.8) MIP

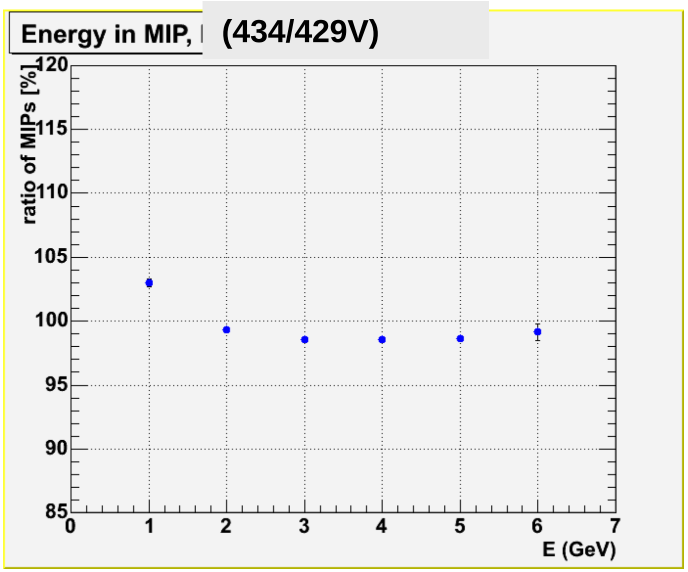
  E_{beam} = 3 – 6 GeV
- ≠0 due to low energies
- measured ADC nonlinearity at small signals (4 -1 %) leads to an opposite effect

- Gain increase by 1.6

  U_{bias}= 429 → 434 V

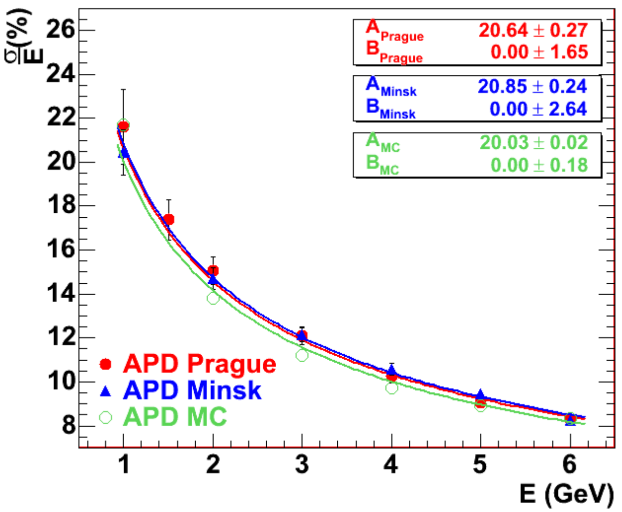
  intercept = -(1.5 ± 1.6) MIP
- Negative intercept is not a problem!

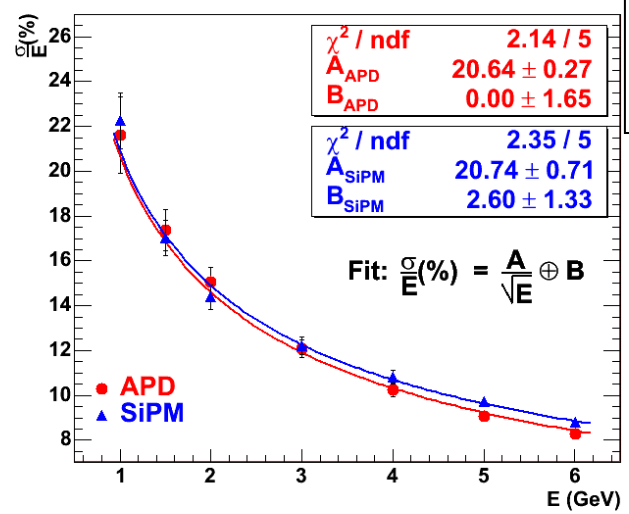




Energy resolution

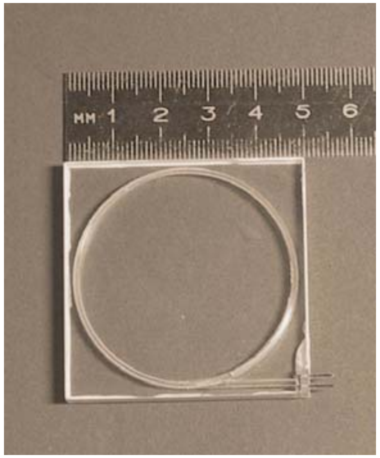
- $$\frac{\sigma_E}{E}(\%) = \frac{A}{\sqrt{E(\mathrm{GeV})}} \oplus B$$
- Data with both preamps are consistent
- Stochastic term for all photodectors is A ~ 21%
- MC stochastic term better by 3-4% with respect to data
- APD measurements not sensitive to the constant term
- Constant term for SiPM B≠0 by 2σ - confirmed by MC





MAPM
1.03/5
21.1±1.1
1.3 ± 4.1

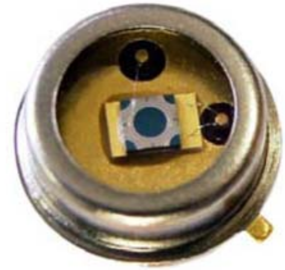
Future option with APD



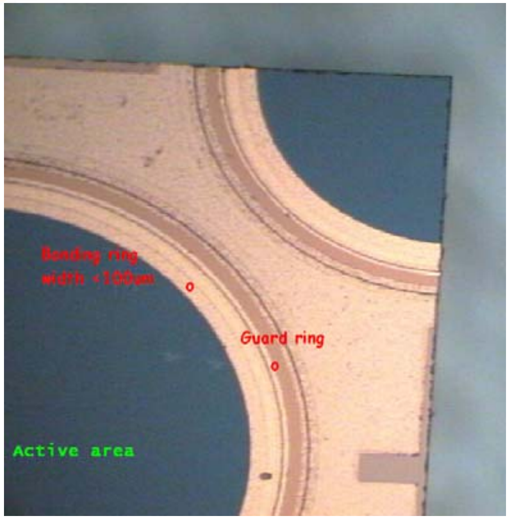
typical geometry with SiPM

- 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

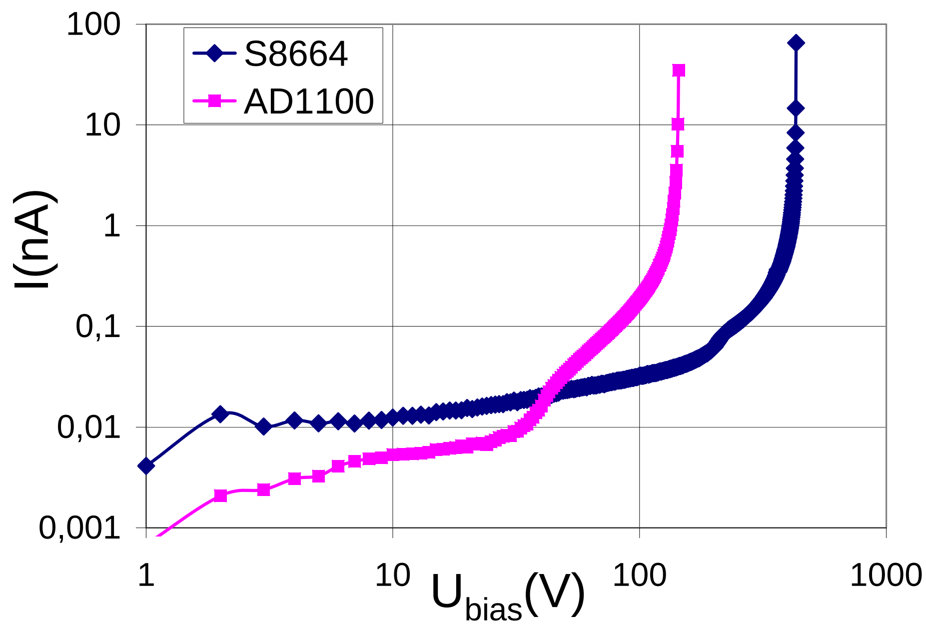


Silicon Sensor
AD 1100



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

- Comparison of new and old APDs



This APD meets some of future requirements

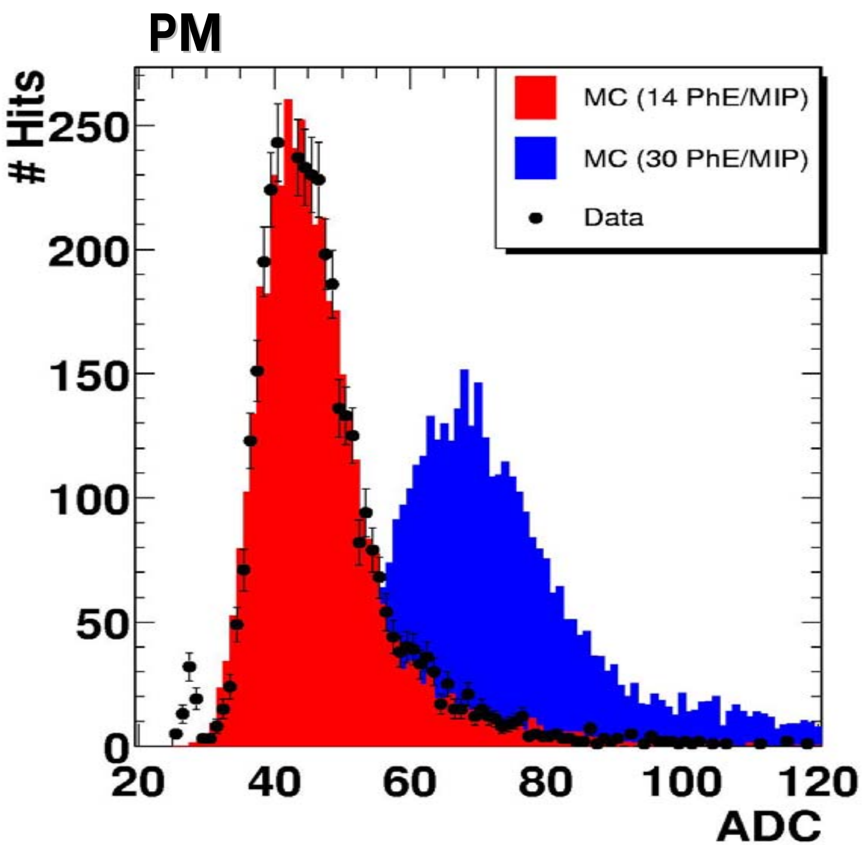
Conclusions

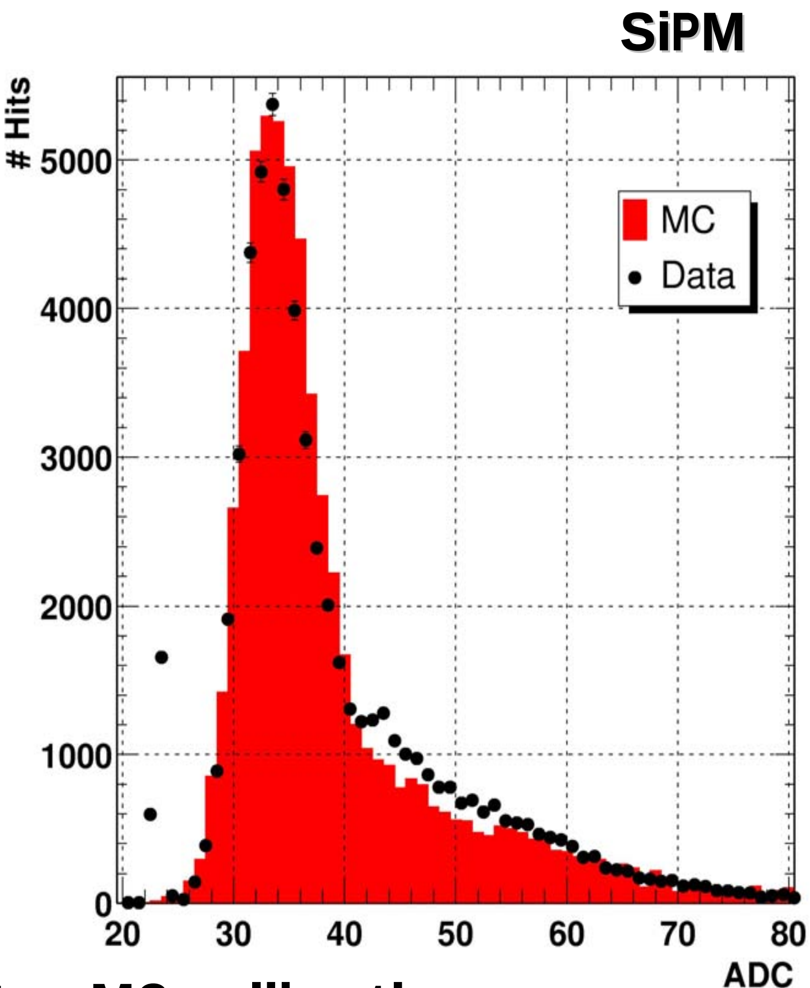
- Successful tests of analog HCAL – MiniCal in the DESY e^+ beam
- Photodectors tested – MAPM, SiPM, APD – give similar results:
  - linear response
  - energy resolution
- APDs were used at room temperatures
- APD have sufficient dynamic range – no saturation effects
- LED calibration system provides 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*

Back-up slides

MC simulation of MIP

- Calibrate MC by adjusting each channel to MIP signal



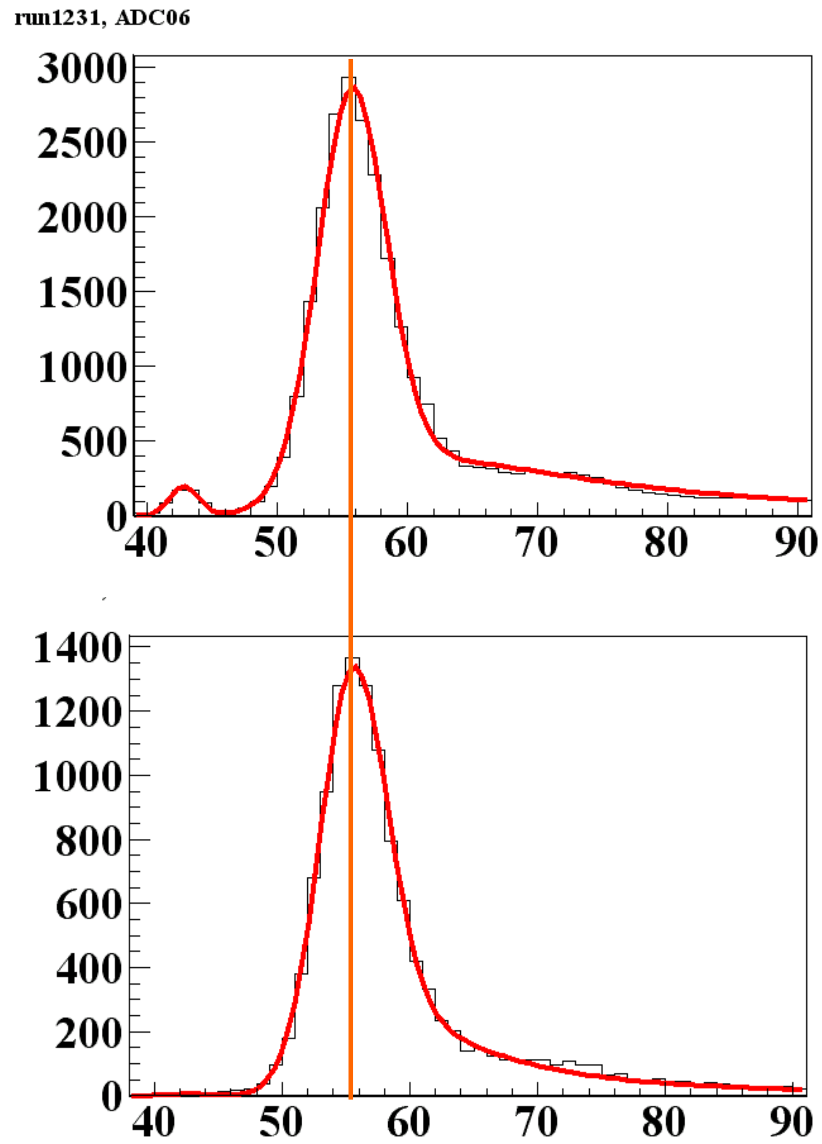


- Good description of MIP shape after MC calibration

from M. Groll

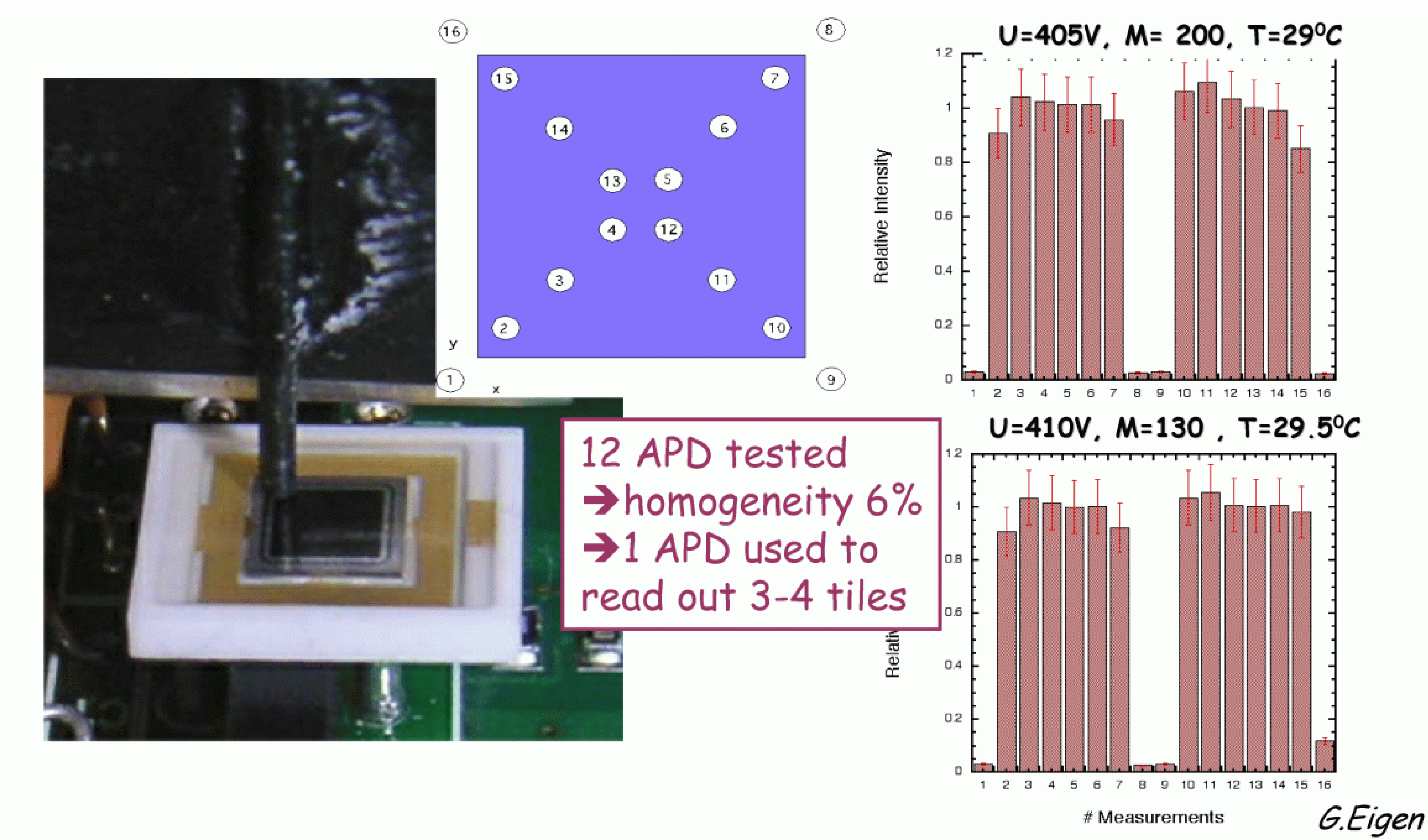
Modification of Calibration Procedure

- 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
➔homogeneity 6%
➔1 APD used to read out 3-4 tiles