Beam Test Studies of Analog HCAL with APD Readout

- Test setup, APDs, preamps
- Calibration procedure
- Gain monitoring with LED
- Beam test results
- Future R&D options

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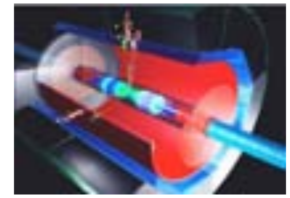
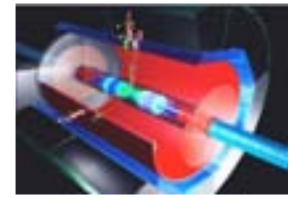
Snowmass- 08/18/05

Introduction

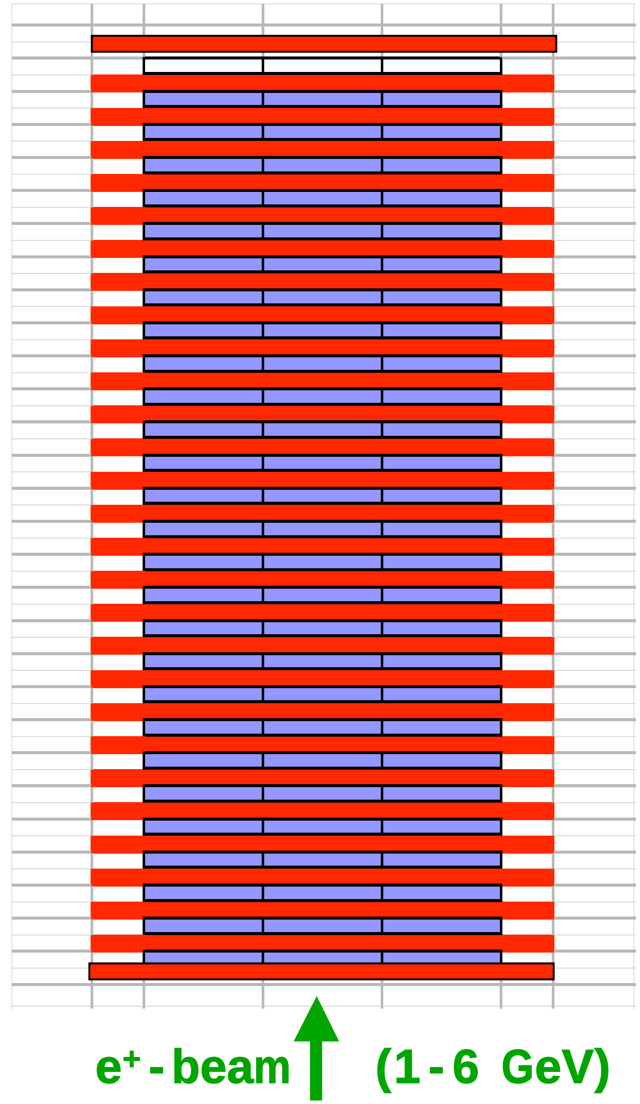


- The analog HCAL group of the Calice collaboration built a small scintillator tile hadron calorimeter prototype, the MiniCal, to perform various studies in a test beam at DESY
  - Perform system tests of selected tile-fiber systems
  - Test performance of various photodetectors
    MAPM → used as reference
    SiPM → (NIM A 540, 368 2005)
    APD's → presented here
  - Establish a reliable calibration procedure for single tiles
  - Monitor system stability & do aging studies
  - Study EM shower development in simulations
  - Test linearity of energy measurements
  - Measure energy resolution of 1-6 GeV e^+ (15×15 cm^2, ~30 X_0)

The MiniCal Prototype

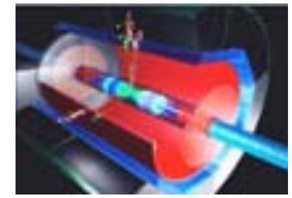


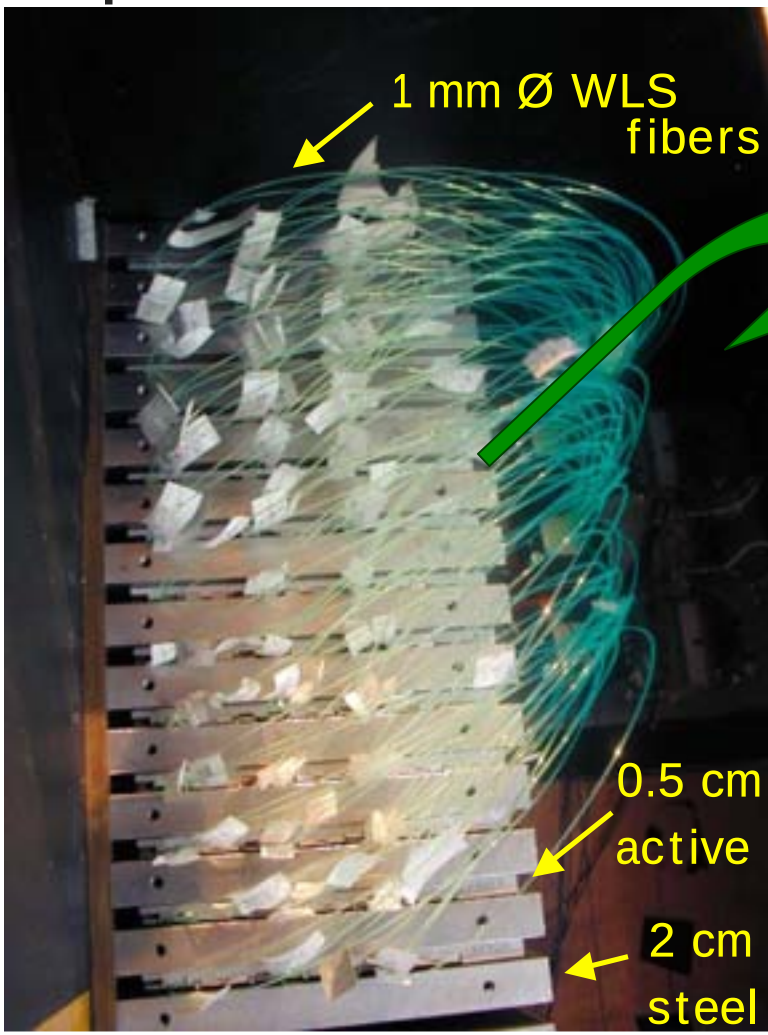
- The MiniCal is a 27-layer Fe/scintillator sandwich structure
- Each layer consists of 2 cm thick stainless steal plates and 9 5×5 cm^2 0.5 cm thick scintillator tiles housed in a cassette ➔ (~1.15X_0 & 0.12λ)
- The first 12 layers are read out with 32 APD's plus center tile of layer 13
- Test configuration in DESY test beam 1-6 GeV e^+

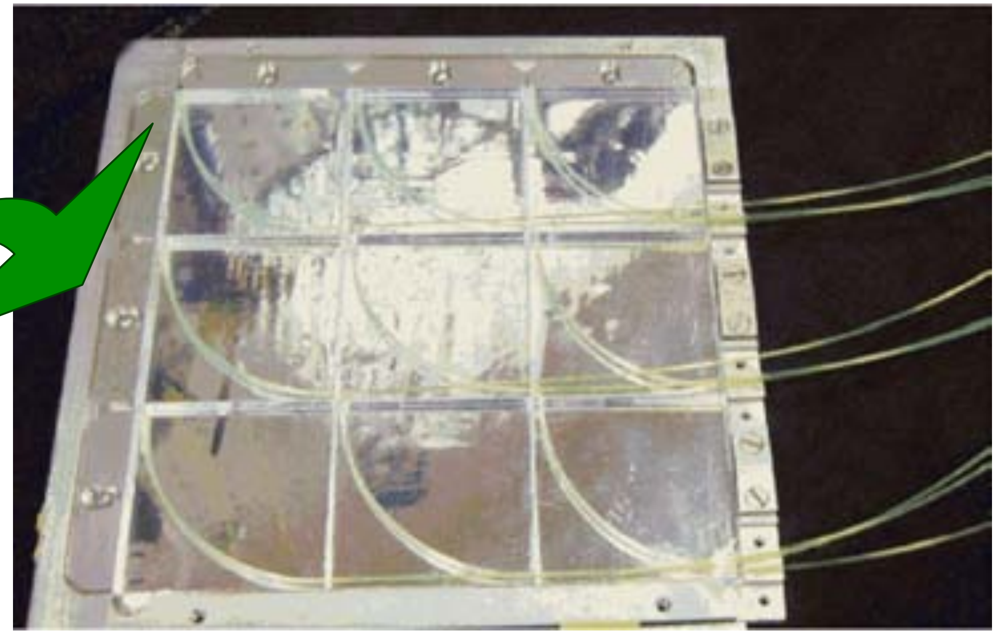


97% of 6 GeV shower is contained in 12 layers

MiniCal Tile Readout



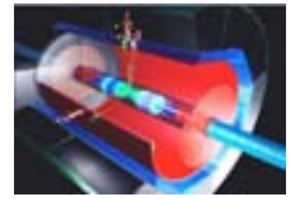




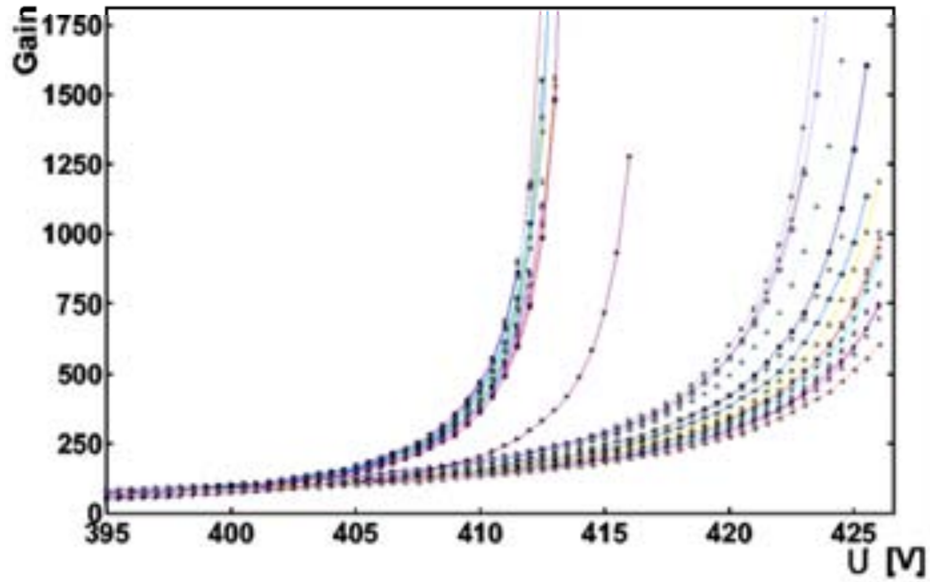
<u>Cassette</u>

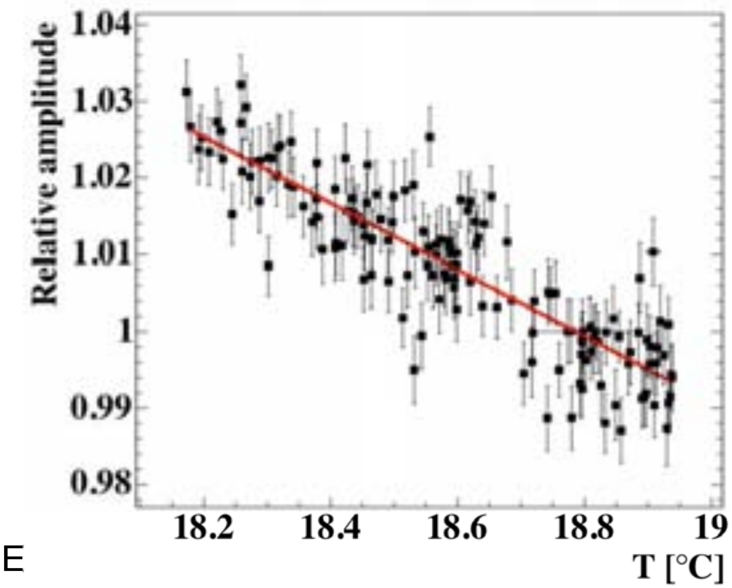
- 9 tiles, each 5x5x0.5 cm^3
- Scintillator (Bicron BC408)
- WLS fibers (Kuraray Y11)
- 3M super reflector (top, bottom)

APD Choice

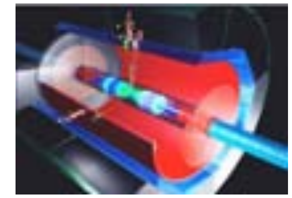


- We use Hamamatsu single-channel APDs S8664-55 special (3x3 mm^2)
- High QE~80%,
- Operate at gains M~100-250
  - → Low noise preamps &
  - → stable power supplies ($\Delta U/U \sim 10^{-4}$ for 1% gain stability)
  - → stable temperature ($1/M\ dM/dT \sim -4.5\%/\mathrm{deg}$)
- Capacitance 30 pF (fully depleted)
- Group APDs by similar gains
- Need temperature and HV monitoring



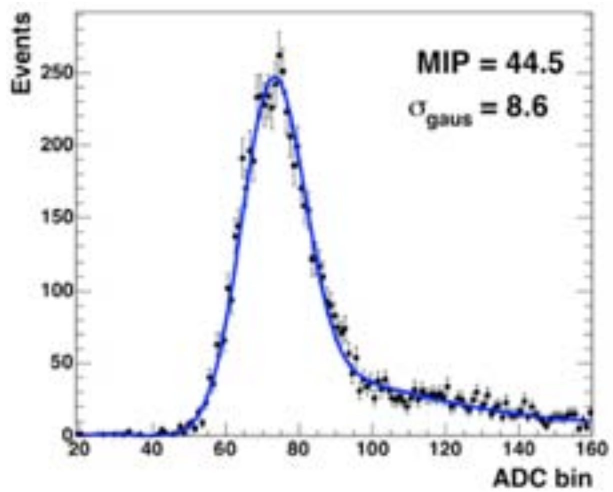


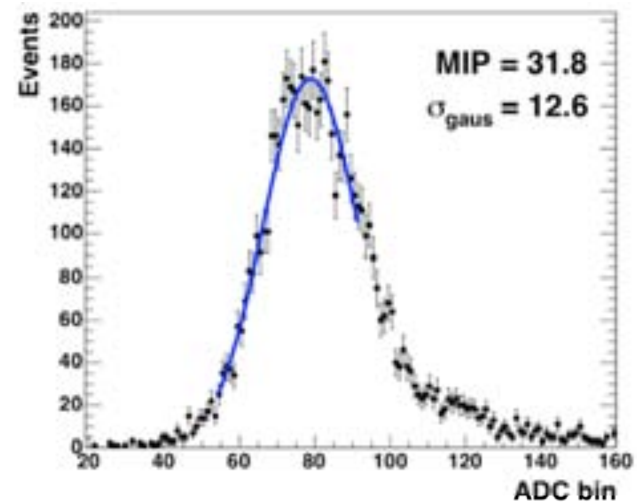
Comparison of Preamplifiers



	Minsk preamp	Prague preamp
❒ Type:	Charge-sensitive	Voltage-sensitive
❒ Signal extraction:	$\int$Q dt & shaping	Peak sensing & shaping
❒ Rise/Fall time:	70 ns/350 ns	40 ns/180 ns
❒ Voltage supply:	5 V	10-12 V

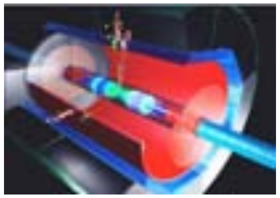
- Minsk preamp has better S/N 9.7±2 ⇔ 3.4±0.7, is smaller in size & has lower power consumption





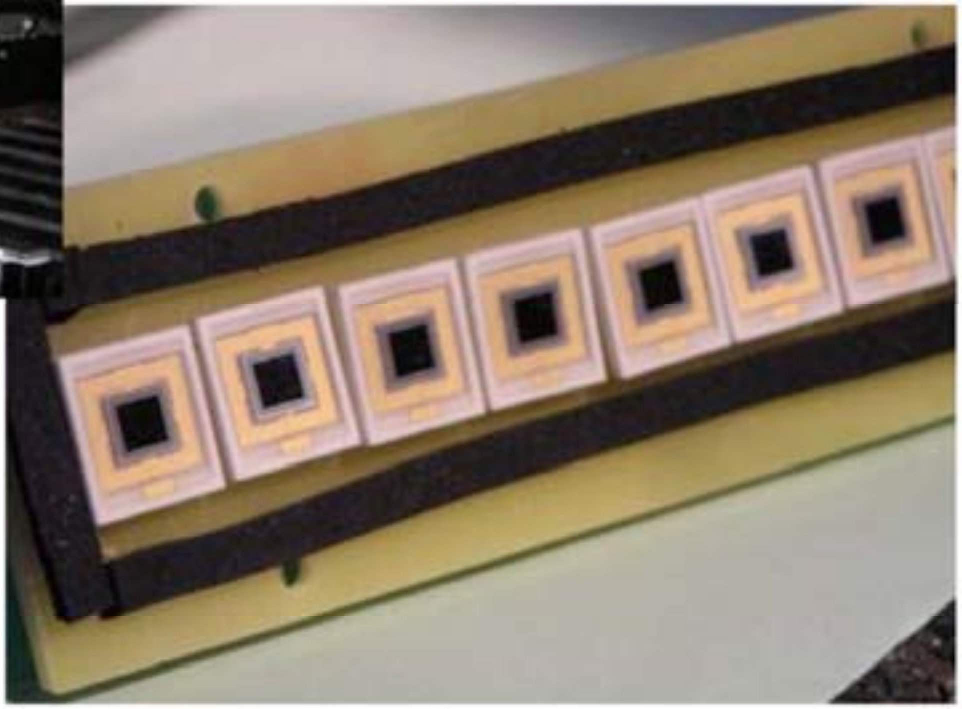
- Prague preamp has higher dynamic range, better linearity, lower Xtalk
- Test beam results are not affected by differences in properties

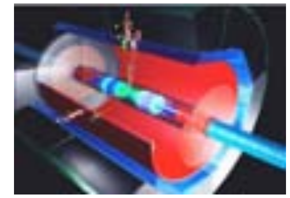
APD Mounting



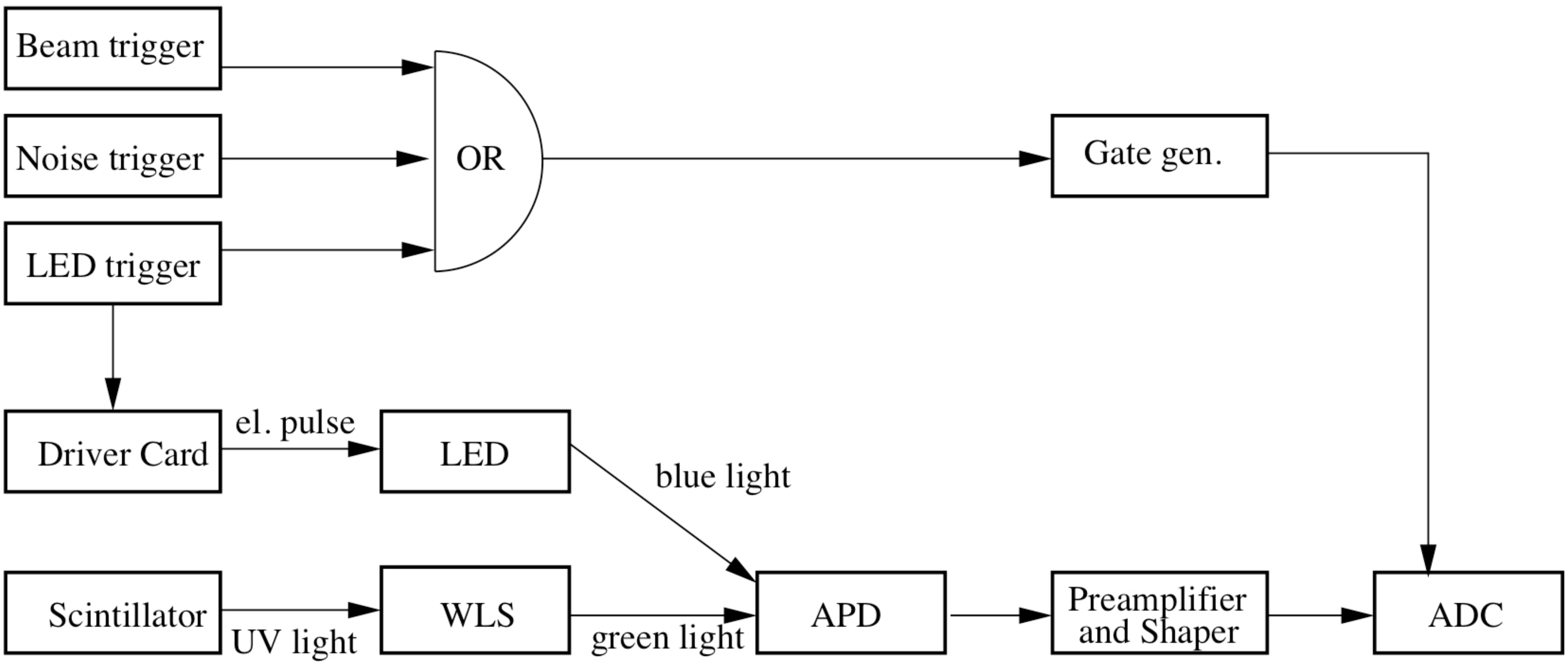
- 9 APDs inserted on mask that is mounted to Prague preamplier

- APDs mounted to Minsk preamplifiers

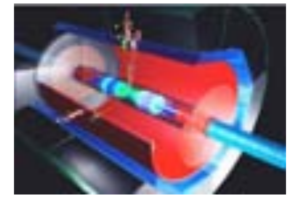




Trigger & DAQ Logic

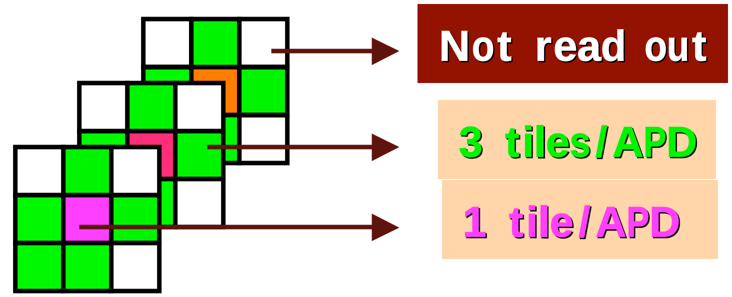


- ❐ Use 11bit ADC (Le Croy 2249W) with CAMAC-based DAQ



Measurement Procedure

- APD Readout scheme:
  - center tiles: individually, layers 1-13
  - edge tiles: 3 tiles from consecutive layers, all tiles in layers 1-12
  - corner tiles: 3 tiles of 1 corner from consecutive layers (1-12)

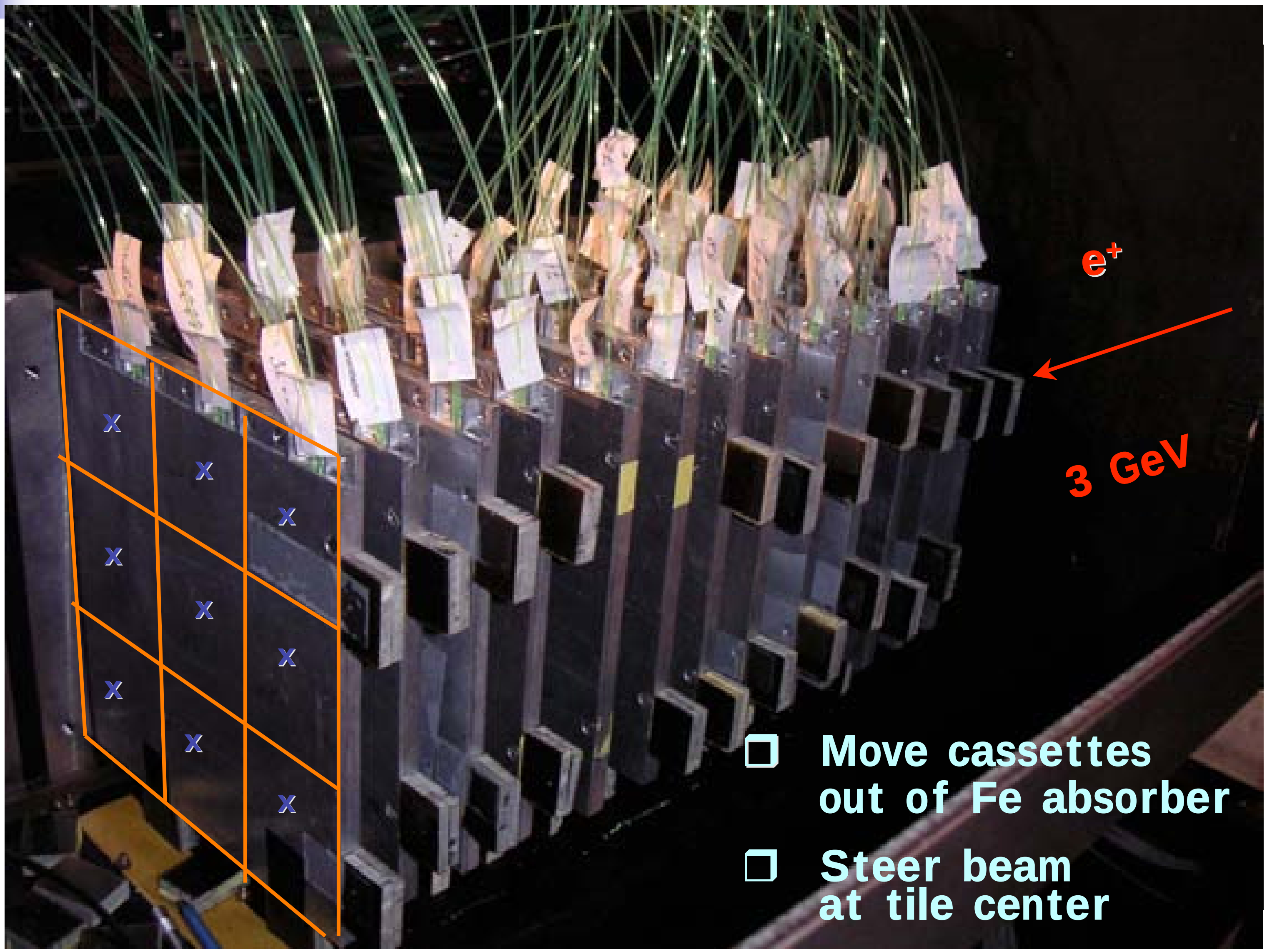


12 layers $\Leftrightarrow$ 13.8 X_0 $\Leftrightarrow$ 1.44 λ

- MIP calibration
  - Use 3 GeV e^+-beam without absorbers
  - Aim at tile centers along z axis (6 positions)
  - Extract calibration factors for each channel

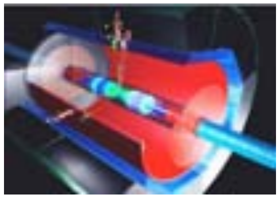
- Energy scan
  - Use beam energies E_b from 1 to 6 GeV
  - Determine response in tiles in MIPs
  - Sum up energies of all tiles (in MIPs)

Calibration Setup

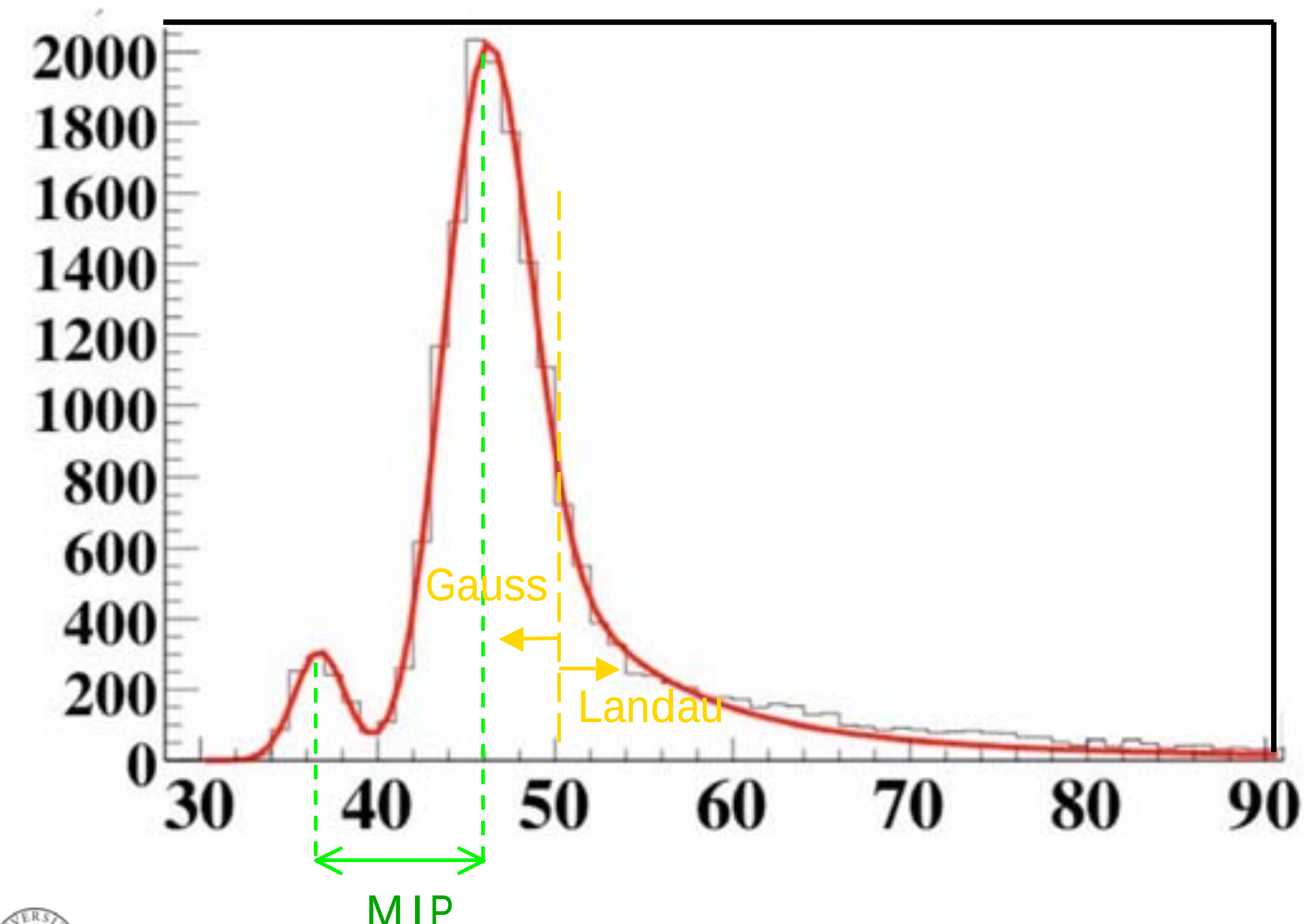


- Move cassettes out of Fe absorber
- Steer beam at tile center

MIP Calibration with 3 GeV e^+



- MIP = Peak – pedestal

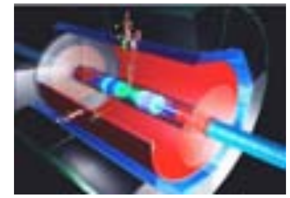


- **Perform Fit:**
  Gaussian for ped
  + Gaussian for
  MIP peak position
  & Landau tail for
  sampling flucts.

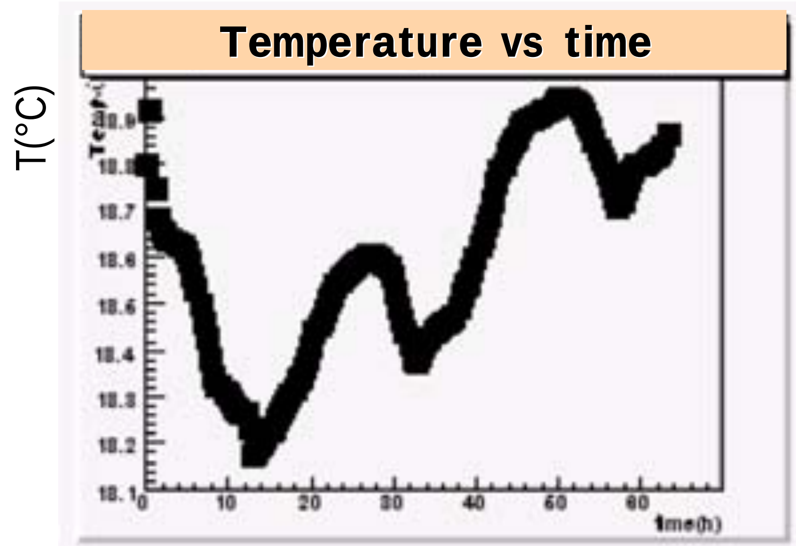
- **Pedestal fit:**
  1 ADC bin shift ⇔
  1% error in σ/E

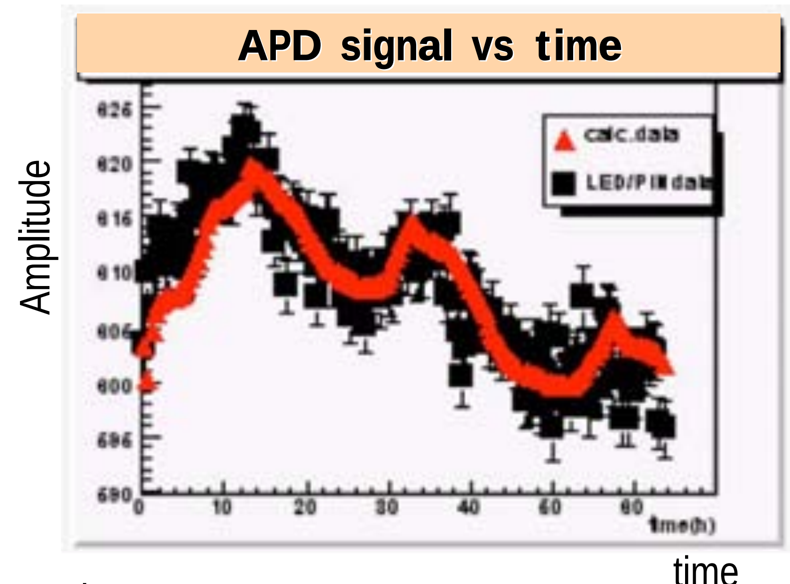
- **Achieve S/σ_{gauss}**
  Minsk: 5.1±0.5
  Prague: 2.5±0.4
  SiPM: 3.7±0.1

APD Gain Monitoring with LED



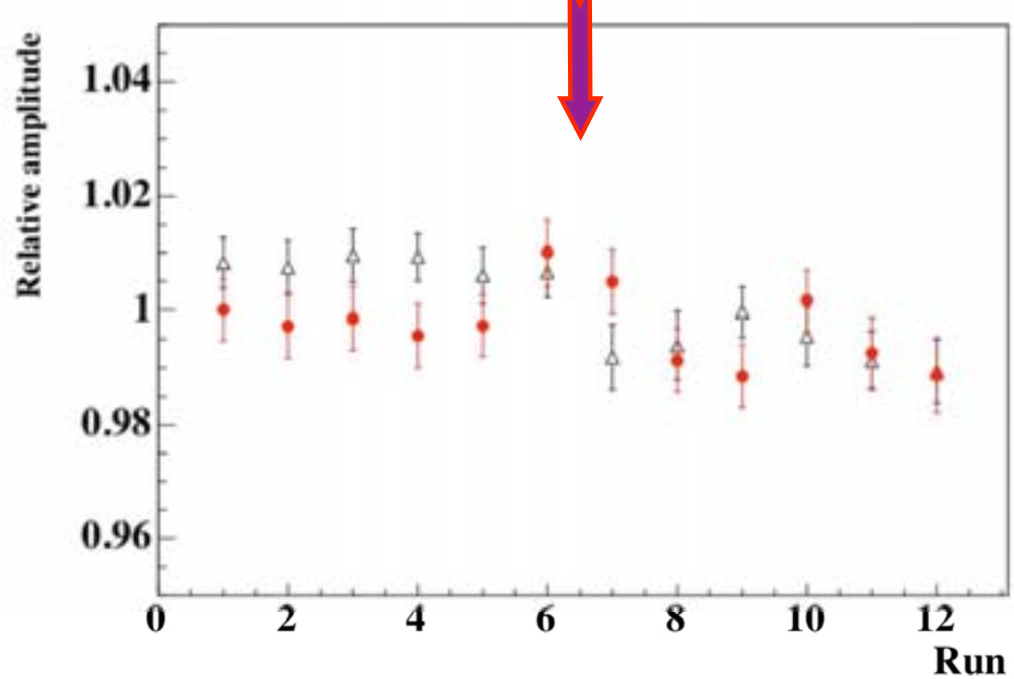
- Feed blue LED light to all APDs via clear fiber at 10 Hz
- Monitor LEDs with PIN diodes
- 84h period monitoring shows:
  - Temperature variations are <1^{0}C
  - T dependence & APD dependence show mirror behavior
  - APD gain changes are well described by T variations
    - ➔ Perform corrections offline
- Typical test run period is ~ 5h
  - APD's are stable within 1%

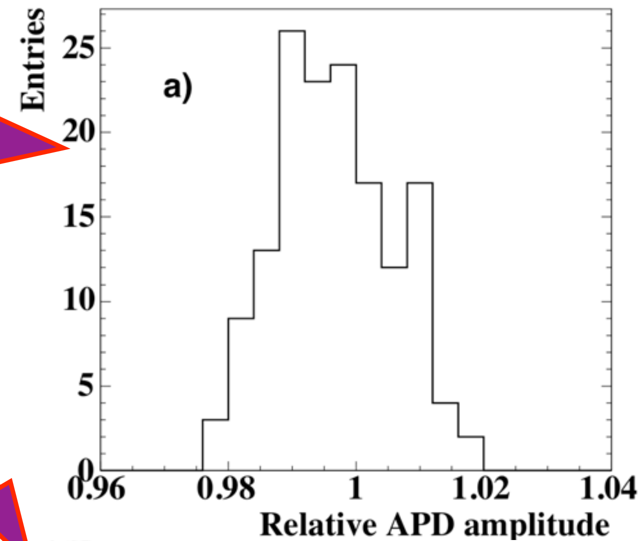


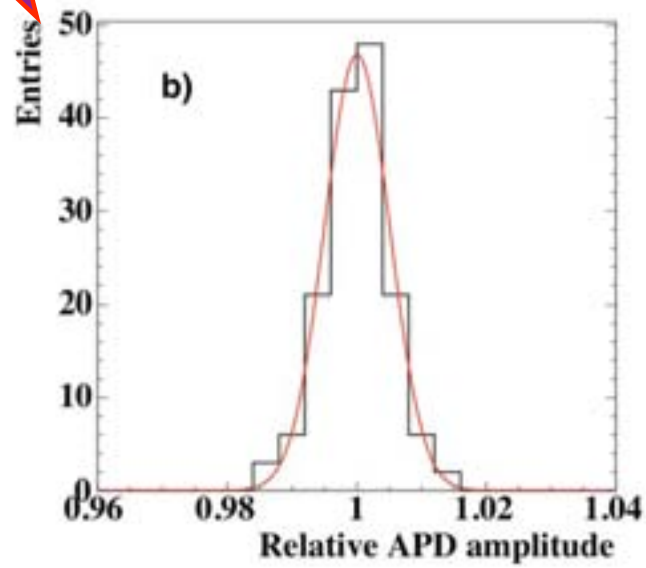


Results of APD Gain Monitoring

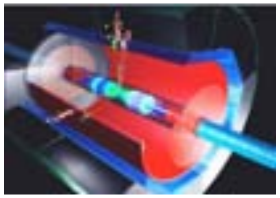
- Uncorrected APD signal from 84h period is not Gaussian
- Gaussian shape is restored after T & PIN diode corrections
- For test beam data T & PIN diode corrections are of order of ~1%







Simulation of APD Data

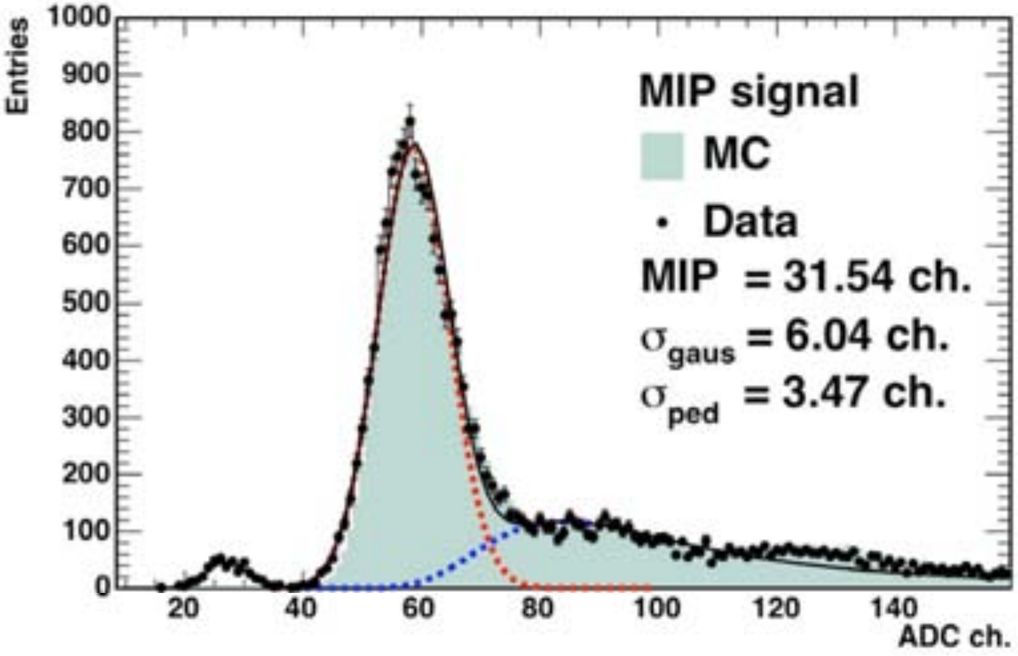


- Need to relate E_{dep} to N_{ADC} in MC

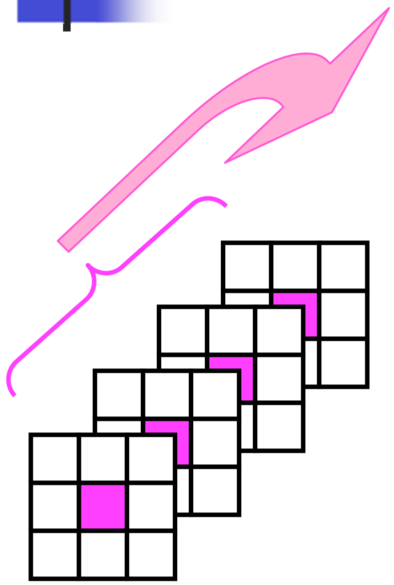
$$N_{ADC} = \frac{N_{ADC}}{N_{pe}} \frac{N_{pe}}{MIP} \frac{MIP}{E_{dep}} E_{dep}$$

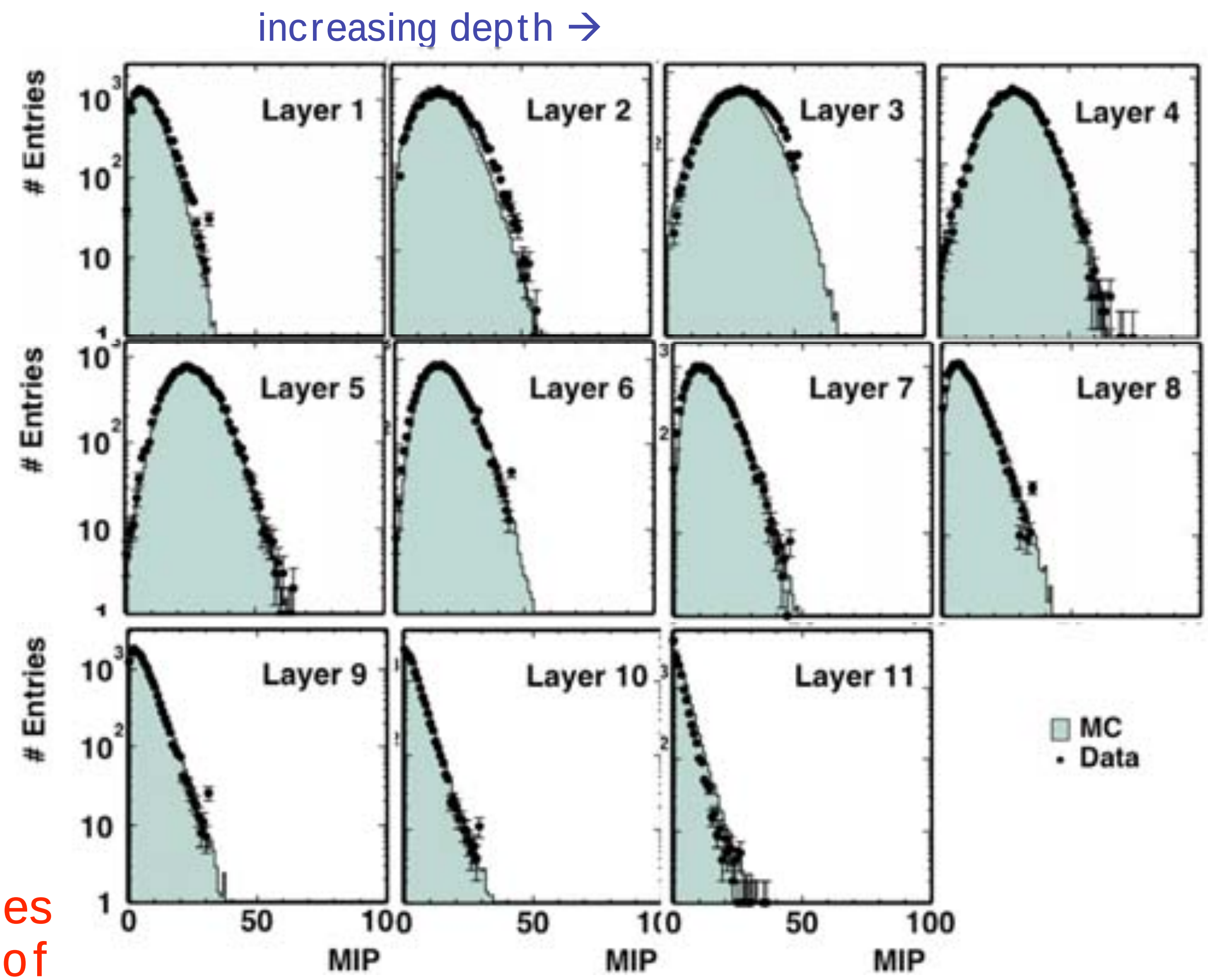
- Need to determine three factors:
  - MIP/E_{dep}: from E_{dep} energy deposited in tile & MIP=810 keV
  - N_{pe}/MIP: determined from MIP signal width in data
  - N_{ADC}/N_{pe}: determined from MIP signal position in data

- MC simulation gives good description of measured energy distribution in a tile



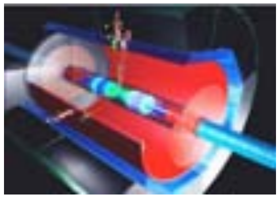
Longitudinal Shower Shape

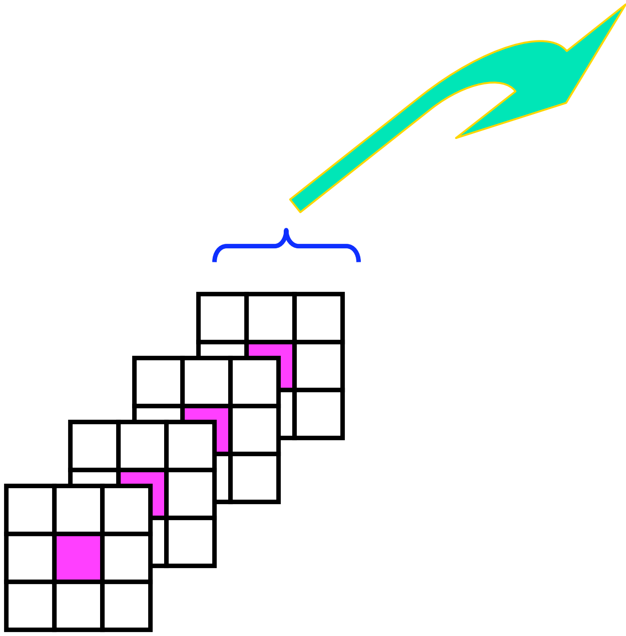


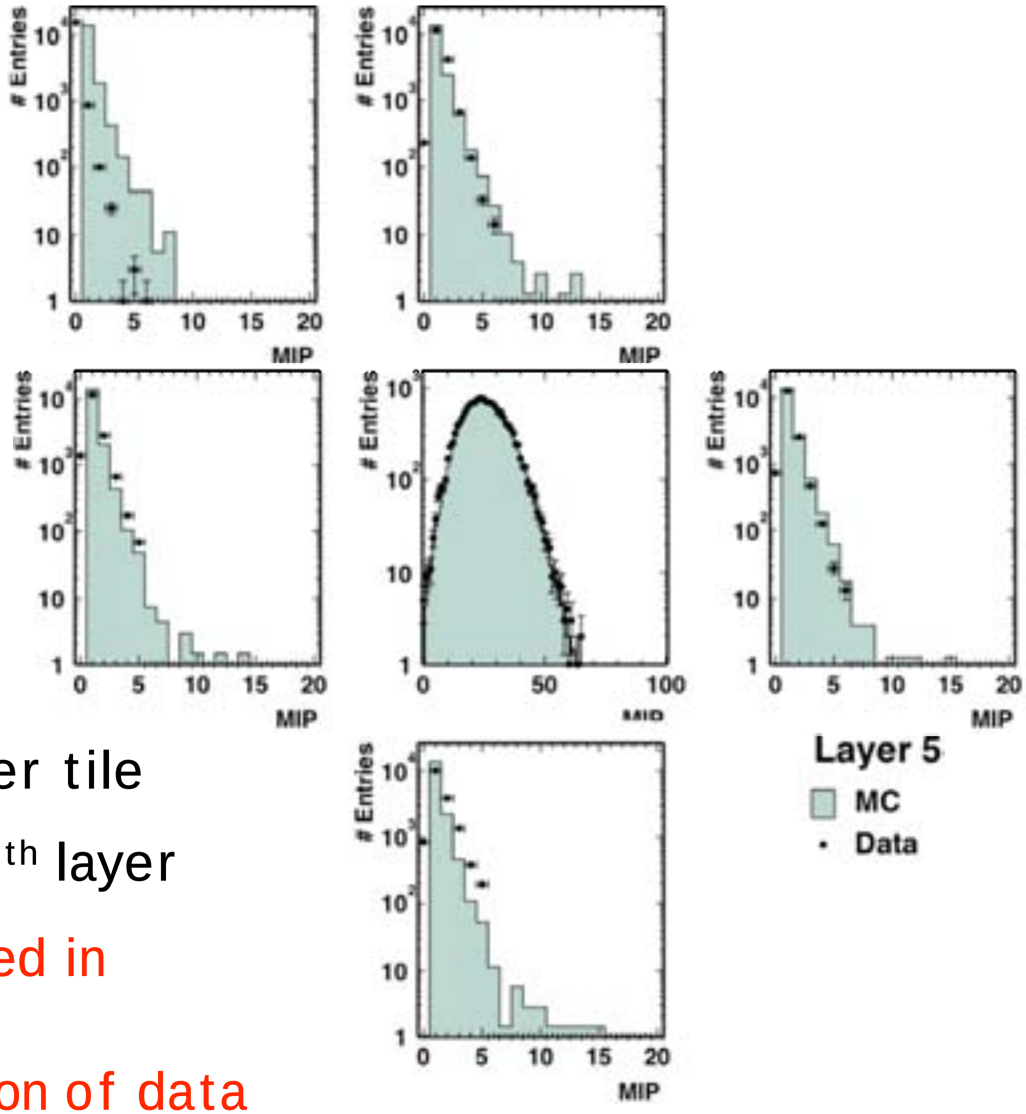


- E_b=5 GeV e^+
- Shower Max is in layers 3-4
- Simulation provides good description of measurement

Lateral Shower Shape



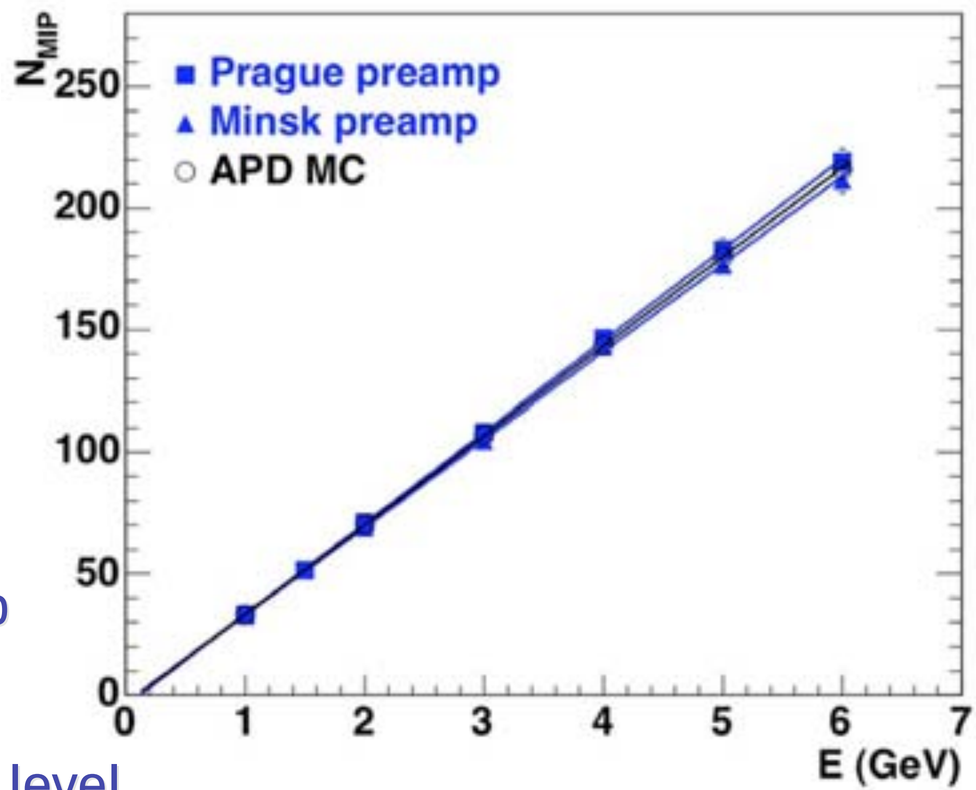




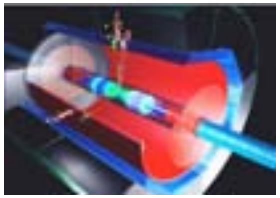
- E_b=5 GeV e^+ shot into center tile
- Look at shower profile in 5th layer
- > 90% of energy is deposited in center tile
- MC provides good description of data

Linearity

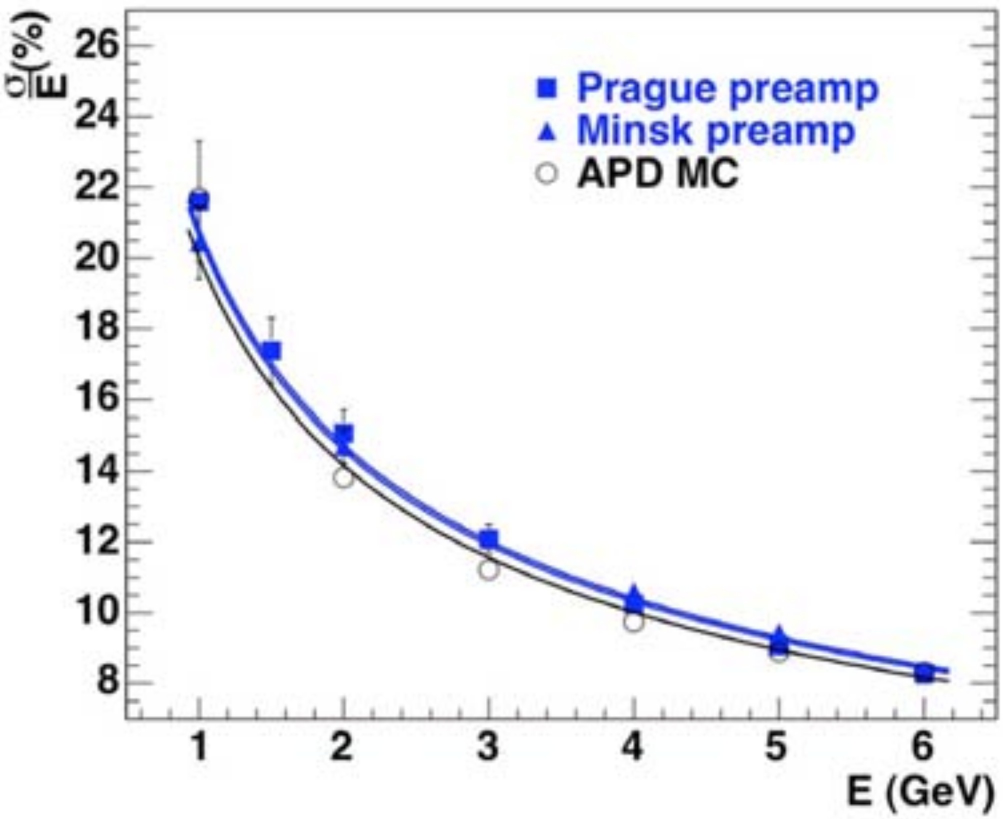
- Sum up MIP contributions of all tiles read out in layers 1-12 for each E_b
- Fit Gaussian to measured distributions to determine most probable value N_{MIP} and resolution σ
- Measured energies & fitted slope parameters of 2 preamp data sets agree within 3%
- See negative intercept at 2σ level
- Get good agreement with simulation
- Get good agreement with SiPM results



Energy Resolution

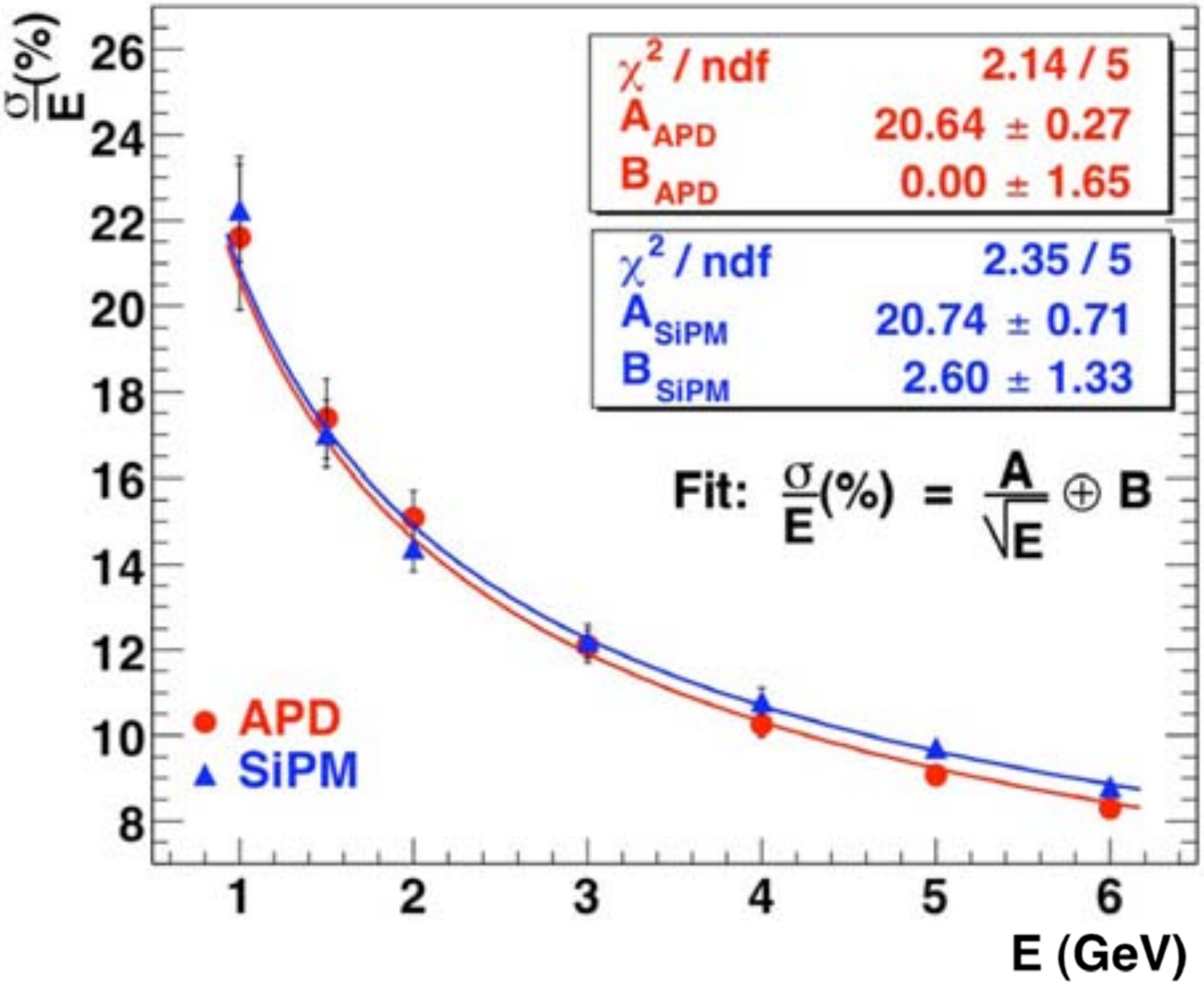


- Fit energy resolution to $\frac{\sigma_E}{E} = \frac{A}{\sqrt{E[\mathrm{GeV}]}} \oplus B$
- Stochastic terms of 2 preamp measurements are in excellent agreement A=21%
- Simulation yields a 3-4% smaller stochastic term wrt data
- Due to limited energy range sensitivity to constant term is reduced (B=0)

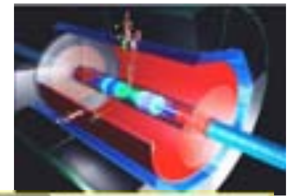


Comparison with SiPM Results

- Good agreement between APD & SiPM results for linearity & energy resolution
- Stochastic terms A are similar
- Constant term B for SiPM deviates by 2σ from zero (confirmed in MC)



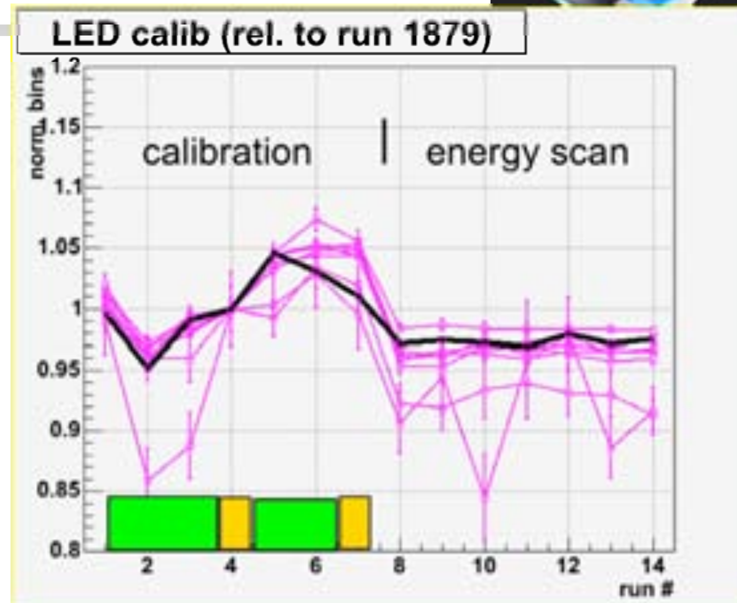
Systematic Errors

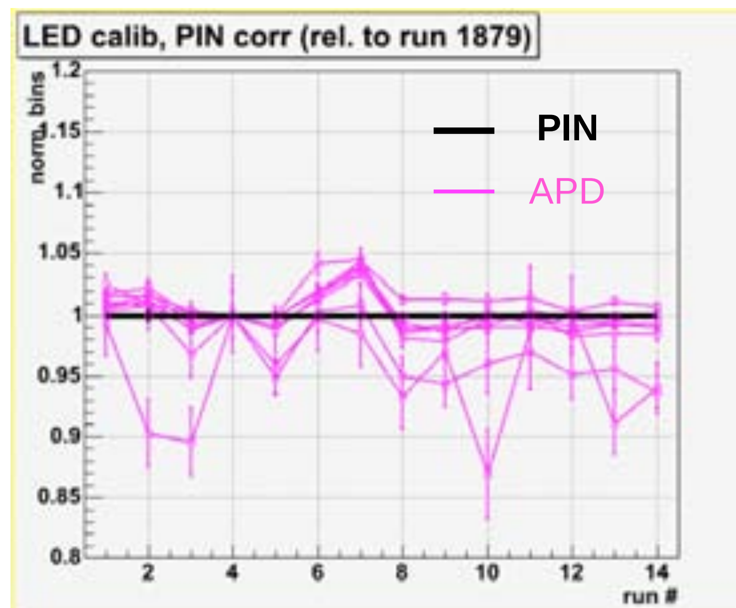


- Record rel LED light of 8 APDs during 7 calibration runs & 7 energy runs (total 5 h)
- Do offline corrections for power supply & temperature fluctuations
  - Systematic uncertainty from time stability is 3%
- Other systematic uncertainties
  - Calibration methods 1%
  - Electronic noise (pedestal) 6%→1%
  - Linearity of ADC 4%→1%
  - Analysis procedure 2%→1%
  - Beam energy spread 6%→2%

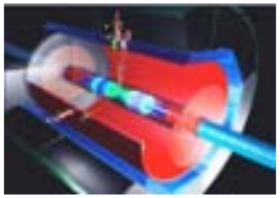
calibration run no.

	6	
3	4,7	5
1	2	



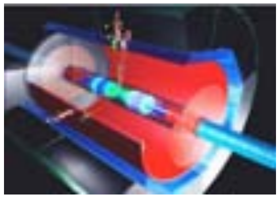


Conclusions



- Studies with analog HCAL “MiniCal” prototype in e^+ beams at DESY were very successful
  - Results for 2 different preamp choices agree well
  - Simulations of lateral & longitudinal shower profiles are consistent with measured profiles
  - Measured linearity is reproduced in simulation, simulated energy resolution is 3-4% better than measured σ_E/E
  - Measurements of linearity & energy resolution for APD readout are in good agreement with those for MAPM & SiPM readout
  - LED monitoring works well to correct for T & HV fluctuations
  - We gained lots of operational experience for physics prototype
- SiPM & APD readout are both viable options for analog tile HCAL
- Presently, we are constructing a 1 m^3 prototype with SiPM readout to study performance in a hadron beam with ECAL in ~1 year

Outlook: APDs in Analog HCAL

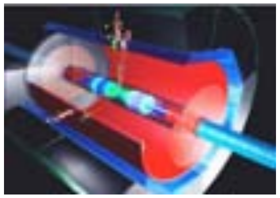


- Particle flow concept requires small cell size
  - for AHCAL: 3×3 cm^2 tiles, individually read out
  - photodetector needs to be located directly on tile

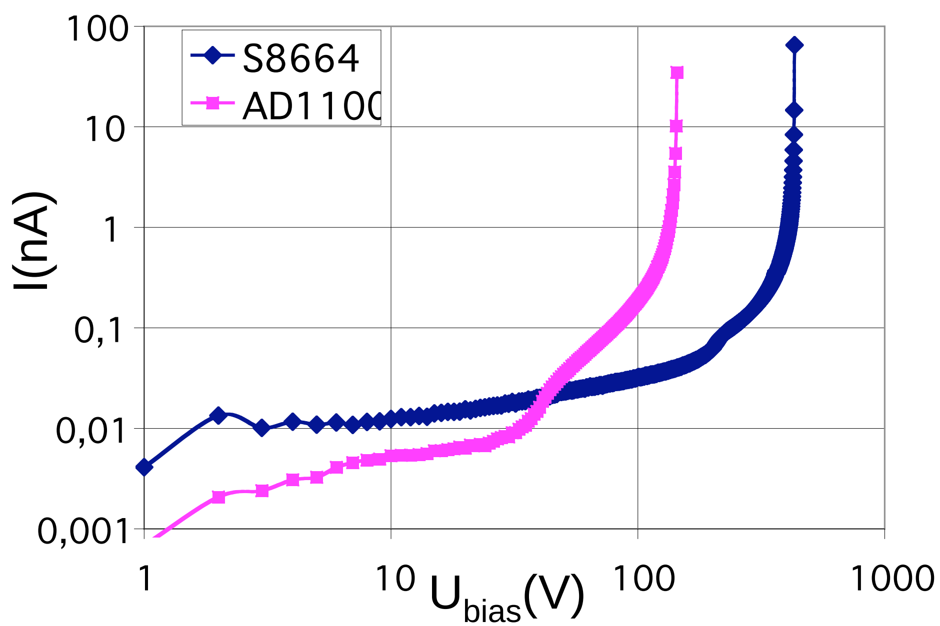
3 cm

- APDs wrt SiPMs have high QE & linear response, but need preamp & stable power supply
- For APD readout need 1×1 mm^2 APD with preamp mounted close to photosensor, low V_{bias}
- R&D on alternative readout without WLS fiber:
  - large-area APDs (25-100 mm^2) with low V_{bias}
  - Scintillators with very long attenuation lengths (>2m)
  - Super reflector foils with high reflectivity for UV/blue light
- Final choice of photodetector will depend on performance, compact arrangement, and cost per channel

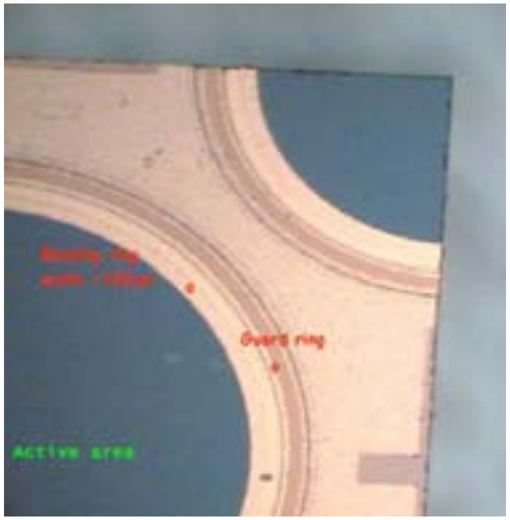
Small-Size APD



- 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

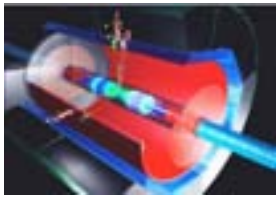


Silicon Sensor
AD 1100



◆ This APD meets some of future requirements

Acknowledgments



- Thanks to all members of HCAL CALICE coll., especially those who contributed to these results:

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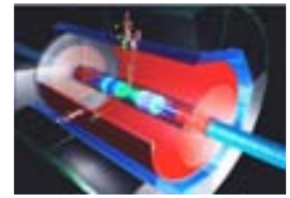
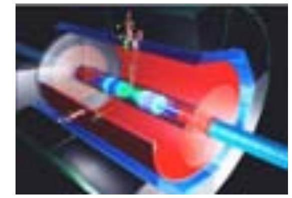
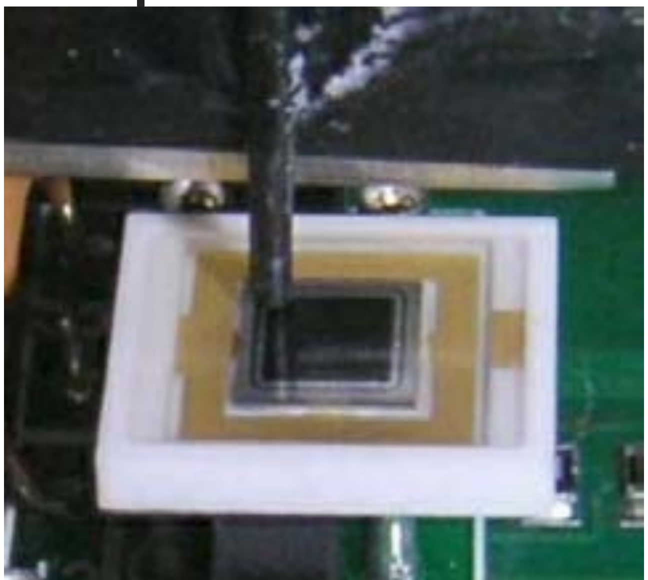
Backup Slides



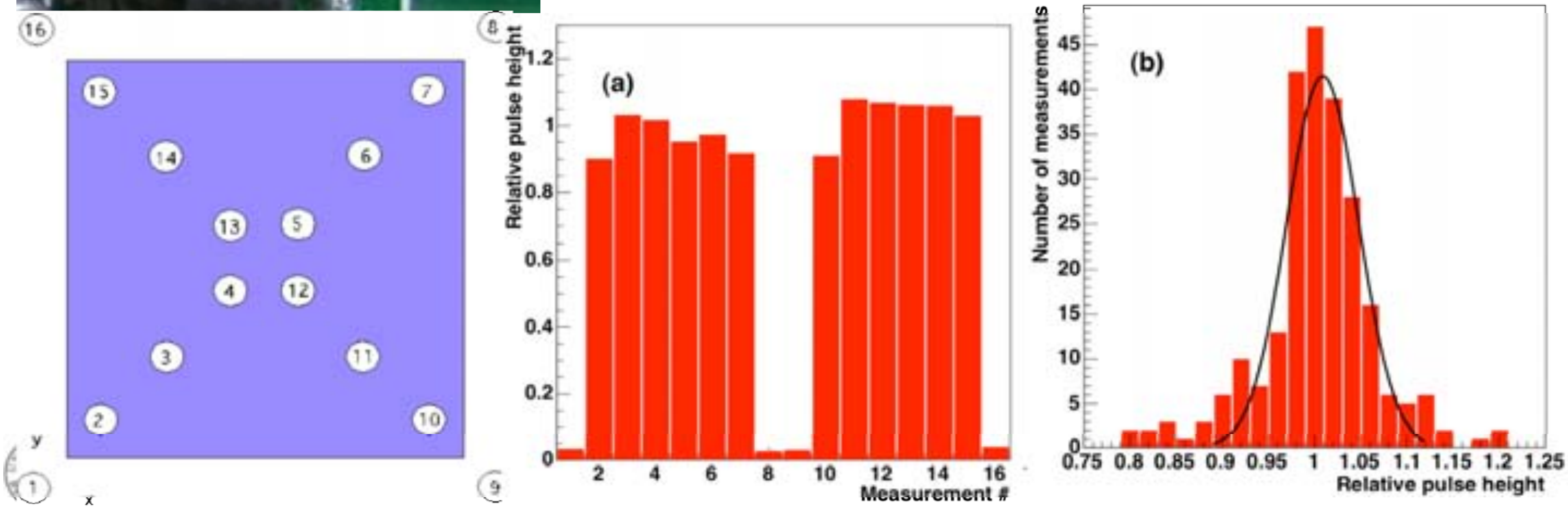
APD Homogeneity



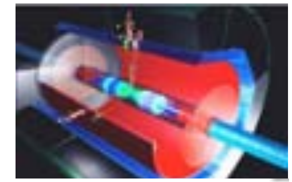


- 21 APD's tested
  - ➔ homogeneity spread $\sigma=3.9\pm0.3\%$
  - ➔ Systematic uncertainty ~ 5%

- 1 APD used to read out 1 or 3 tiles

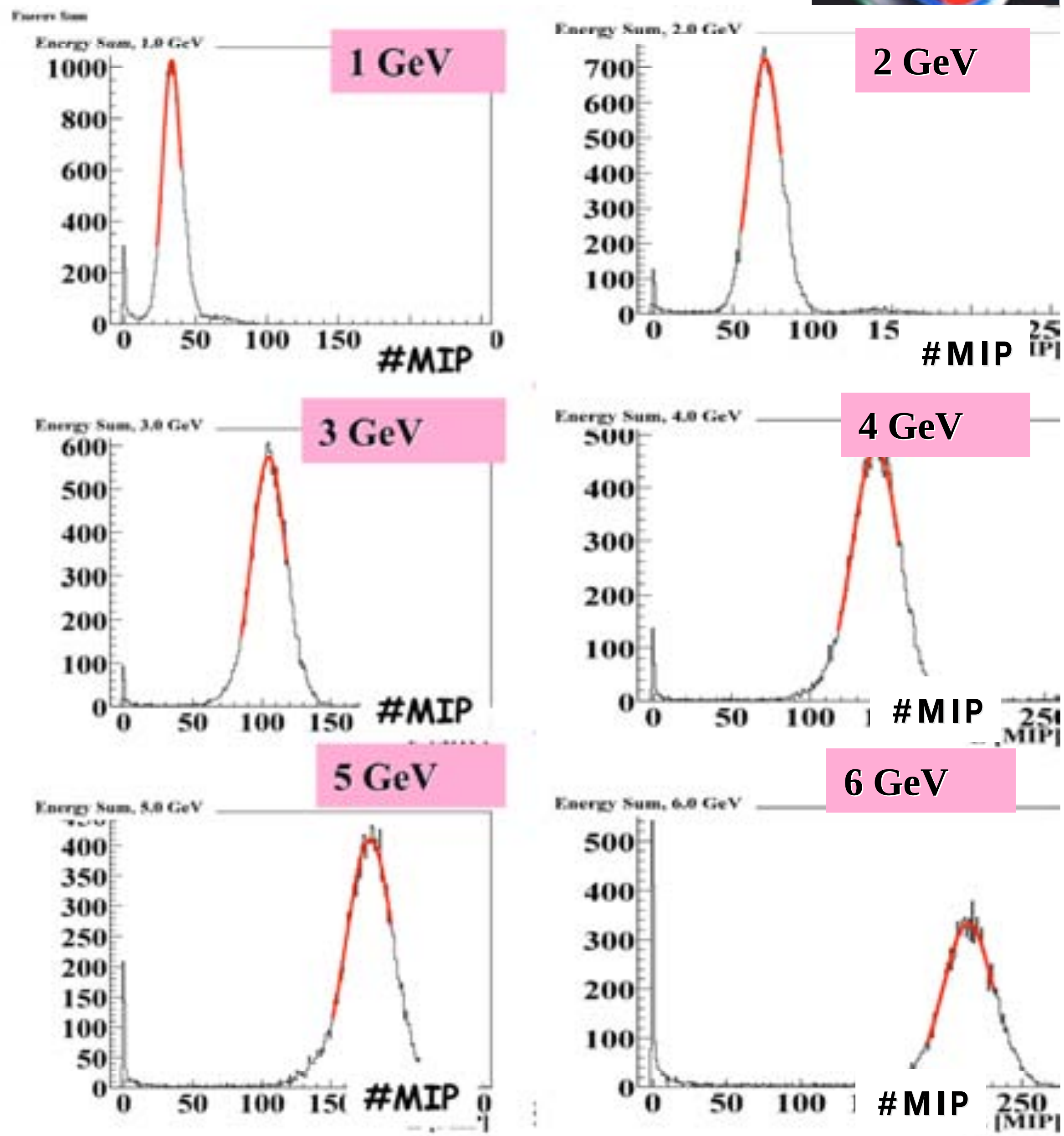


Energy Sums

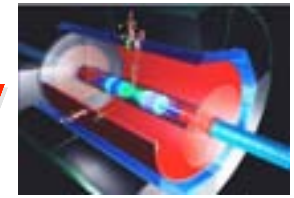


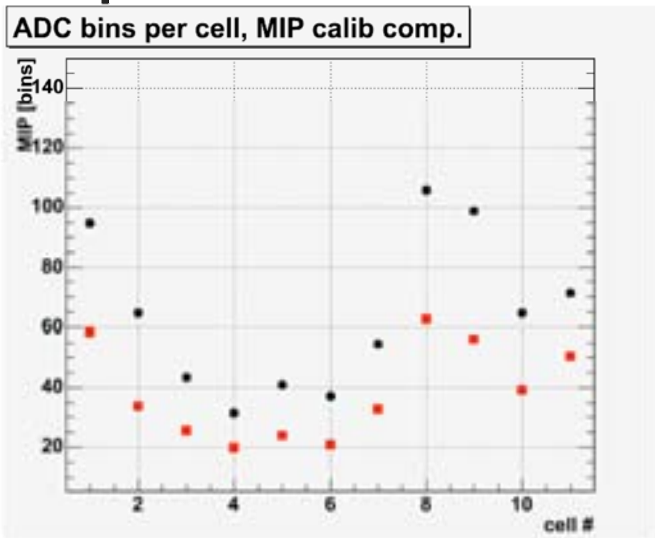
- ❐ **Sum up energies of 93 tiles (in MIPs) for 1-6 GeV beam energies**
- ❐ **Distributions look similar as those for PM & SiPM readout**

  - ➢ **Energy sums for Minsk & Prague preamps look as expected and are in good agreement**

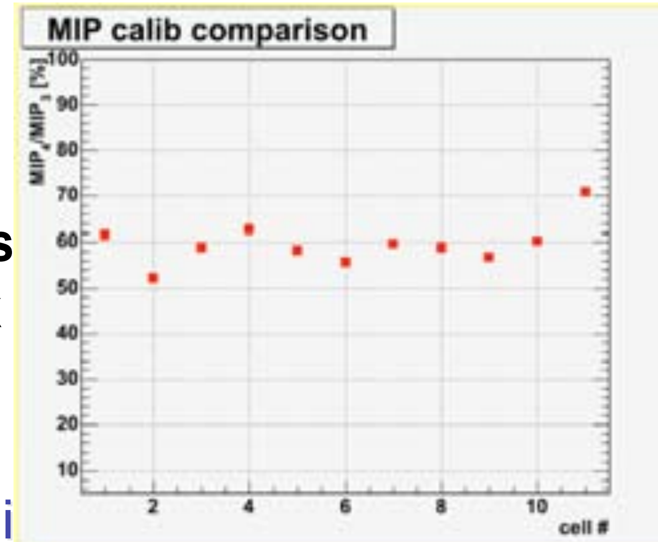


MIP calibration for different HV





- **Prague preamp**
- **HV1 = 434 V**
- **HV2 = 429 V**
- **MIP calib factors for central stack**



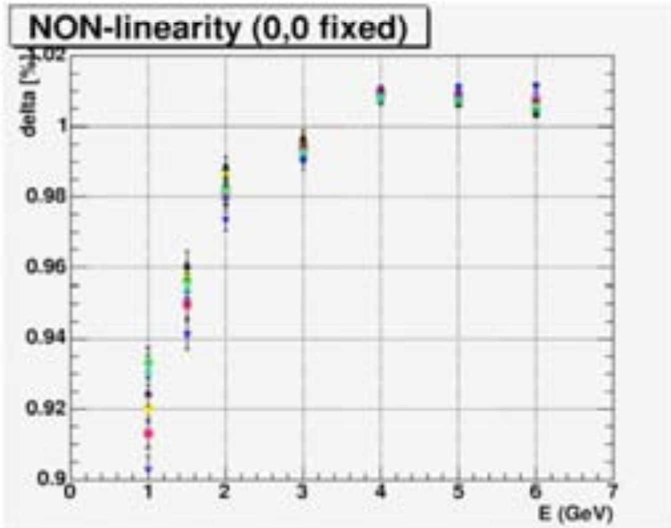
- Compare calibration for 2 data sets with di Prague preamp (gain ratio=~1.67)
- Cell-by cell calibration gives consistent results
- Calibration is well reproducible
- Variation of gate widths from 500 ns to 300 ns has no effects

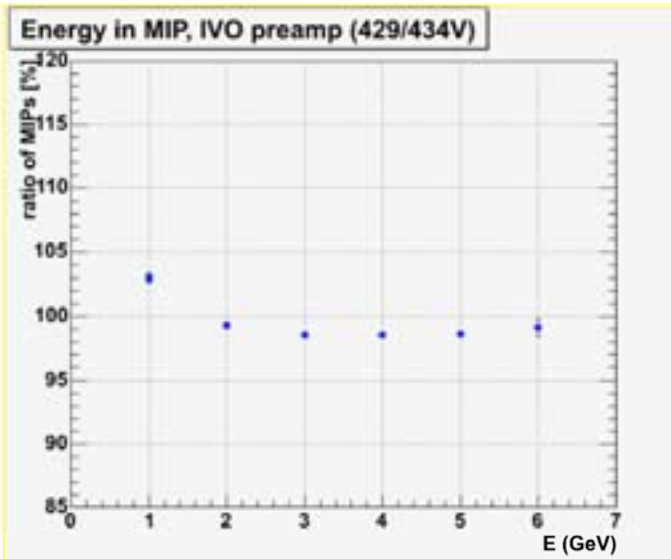
Study of Negative Intercept

- Use 1-6 GeV points in fit yields intercept of -(3.6±1.6) MIP
- Use 3-6 GeV points in fit yields intercept of -(1.8±1.8) MIP

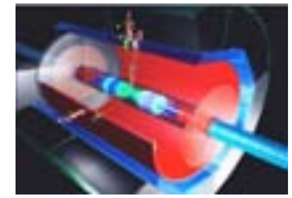
➔ Nonzero intercept is caused by low energy points

- Measured ADC non-linearity of 4%→1% for small signals leads to opposite effect
- Measurements at increased gain of 1.6 by raising U=429 V → U=434 V yields intercept of -(1.5±1.6) MIP





MC Simulation Model



$\#MIPs = \frac{E_{real}}{E_{MIP}}$ $\#pe = \#MIPs * \frac{\#pe}{MIP}$ $ADC_{ch} = \#pe * \frac{ADC}{\#pe}$

Energy deposited E_{real} → Scintillator + tile-fiber → Poisson → APD → ADC

$\#\gamma = \#pe * \frac{\#\gamma}{\#pe}$ $\#pe = f_{SiPM}(\#\gamma, \#pixel, Xtalk)$

- LY variation in scintillator ~5%
- Smearing of pe in photodetector
- non-linearity correction

- Specify material
- Specify geometry

- Calibrate #pe/MIP via signal width

- Calibrate ADC/#pe via MIP signal position