Performance of the ALICE PHOS detector

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OUTLINE

- Physics requirements
- ALICE PHOS detector
- Test with LED or step pulse
- Test with beam
  - Calibration
  - Energy resolution
  - Timing resolution
- Summary

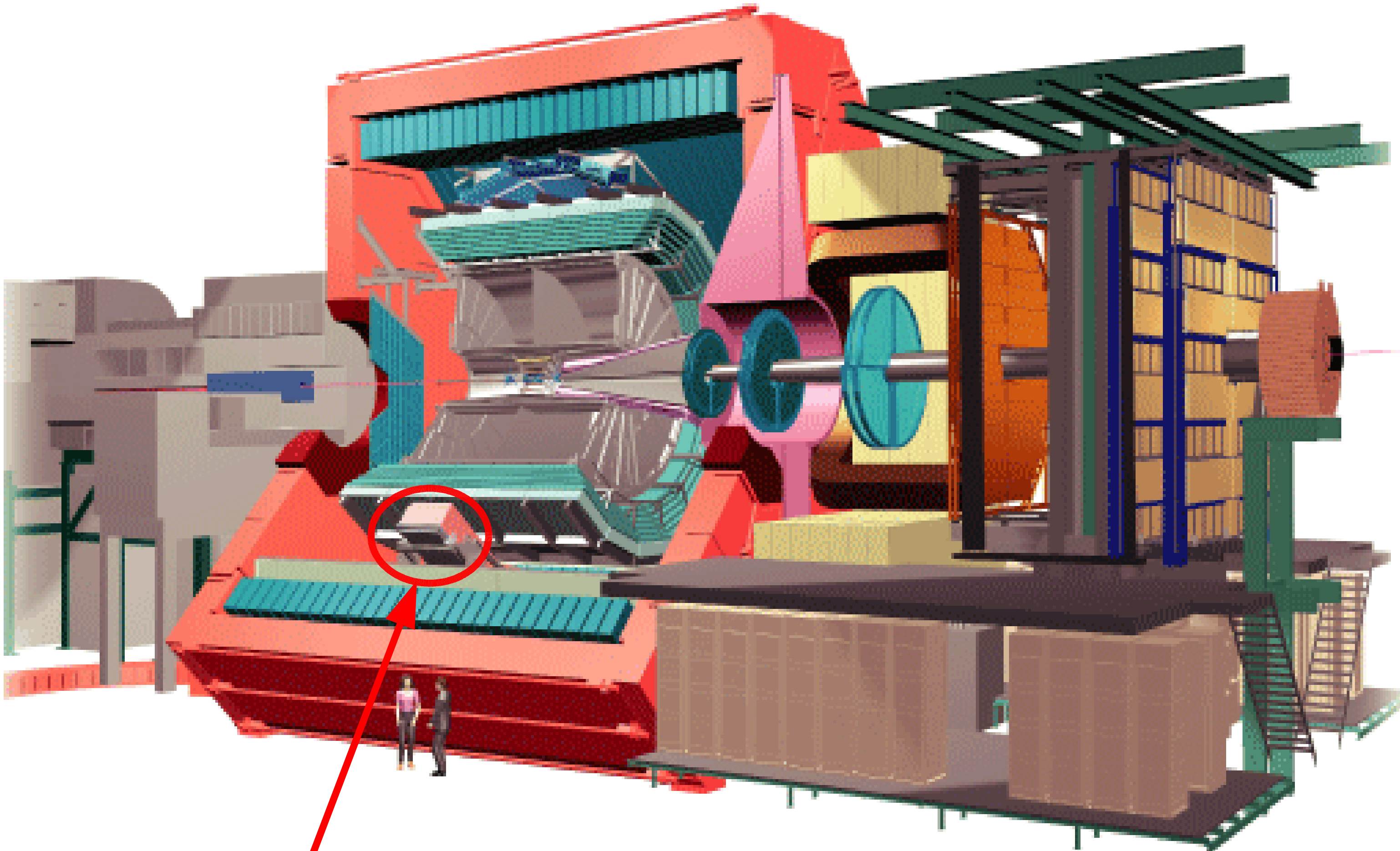
Physics requirements (I)

- **Measure direct photon spectrum to determine the temperature of the initial phase of the heavy ion collisions**
- **Measure π^0 and η p_t spectra up to 80 GeV/c to study both the initial- and final-state effects on particle production**
- **Study parton energy loss and the modification of fragmentation function via γ-tagged jet events**

Physics requirements (II)

- To detect rare signals of most interesting hard probes, it requires PHOS to deliver an L0/L1 trigger to ALICE Central Trigger Processor (CTP)
- To study both soft and hard processes, it requires PHOS to cover large dynamic range with optimal energy resolution
- To discriminate against 1-2 GeV (anti-)neutrons and limit its contamination to a level below 2%, it requires PHOS has a timing resolution smaller than 2 ns at 2 GeV

The ALICE PHOS Detector

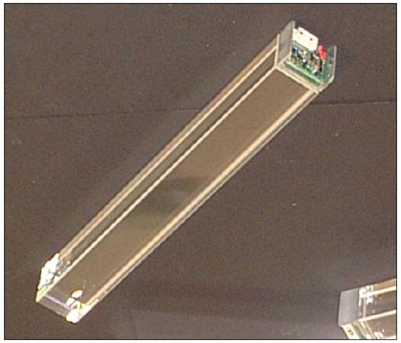


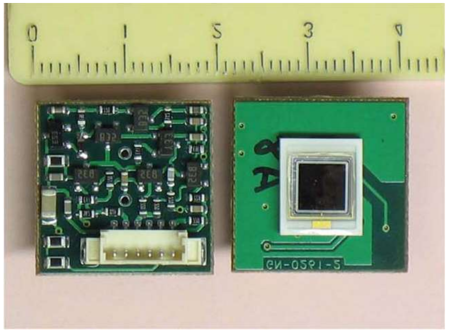
PHOS

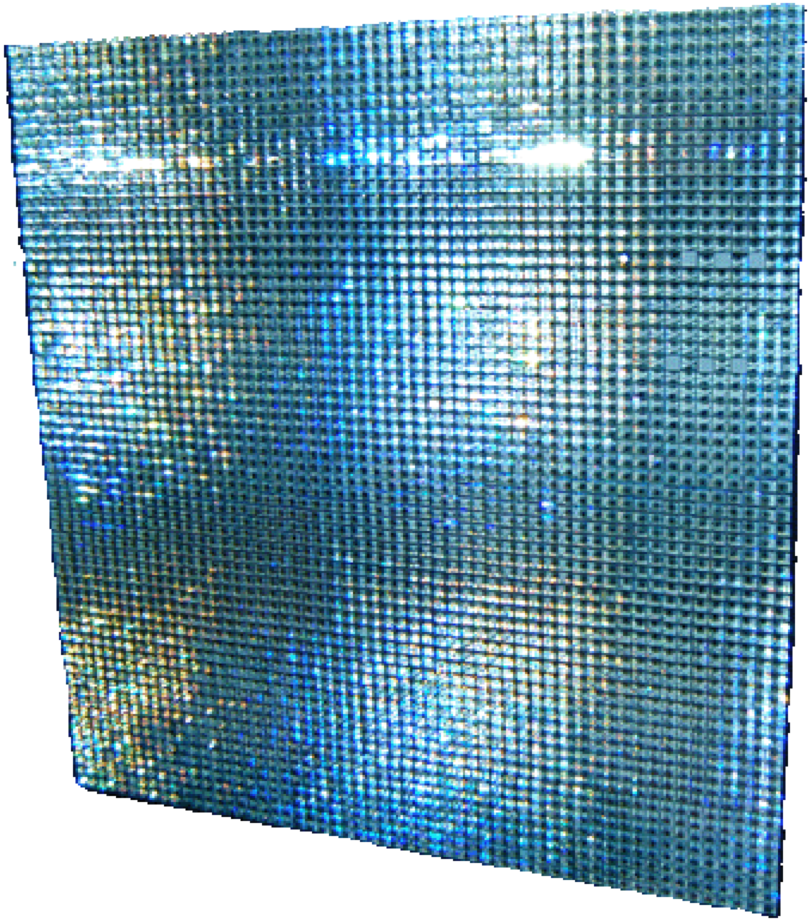
- IP: 4.6m
- Coverage: $|\eta| \leq 0.12$, 100º in azimuthal angle

The ALICE PHOS Detector (II)

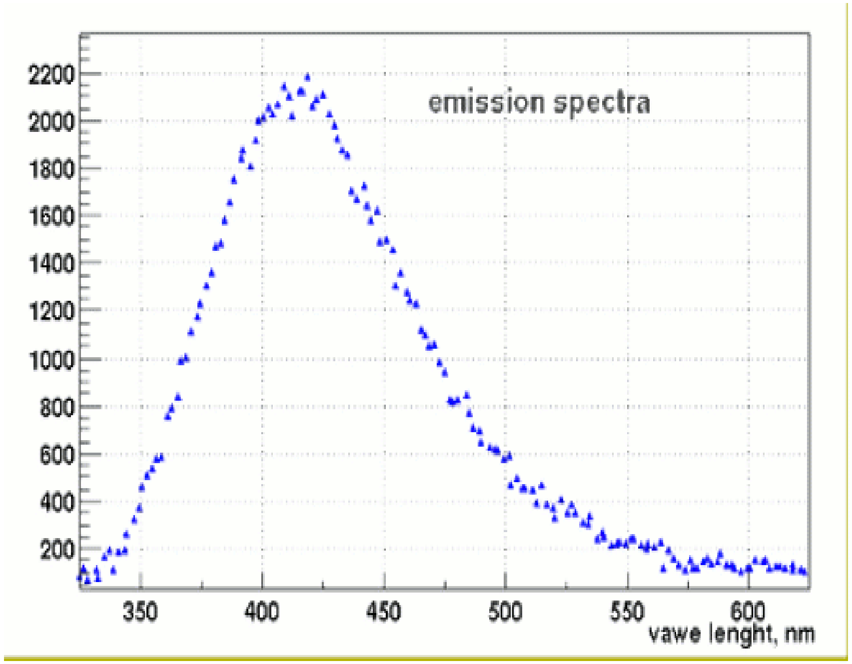
- 5 modules
- Each module consists of 56x64 PWO
- PWO dimensions: 2.2x2.2x18 cm^3
- APD as photo-detector

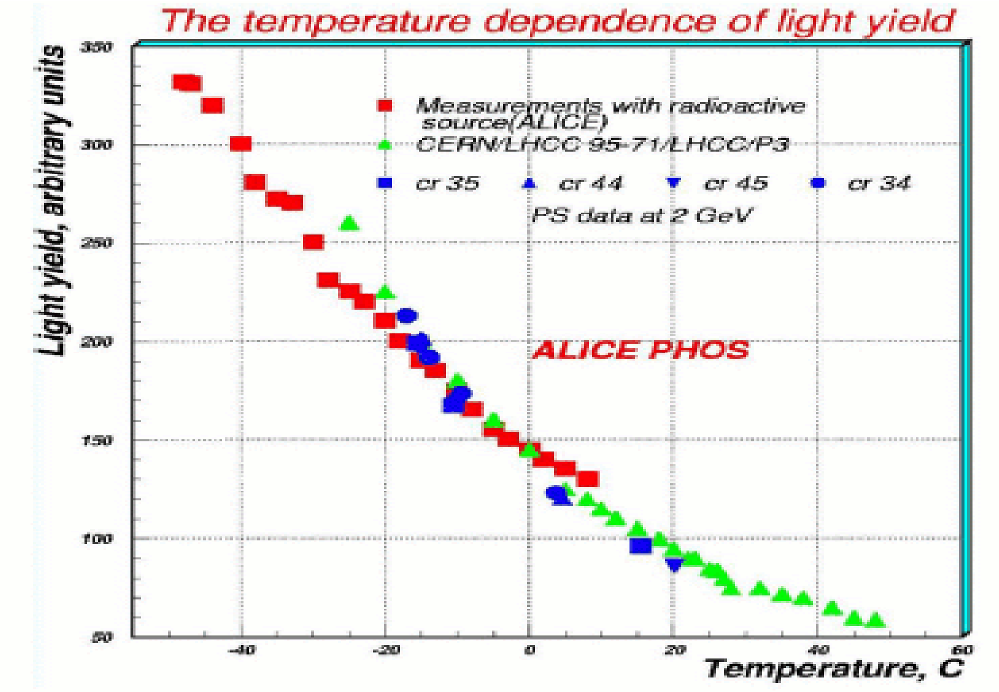






PWO Crystal

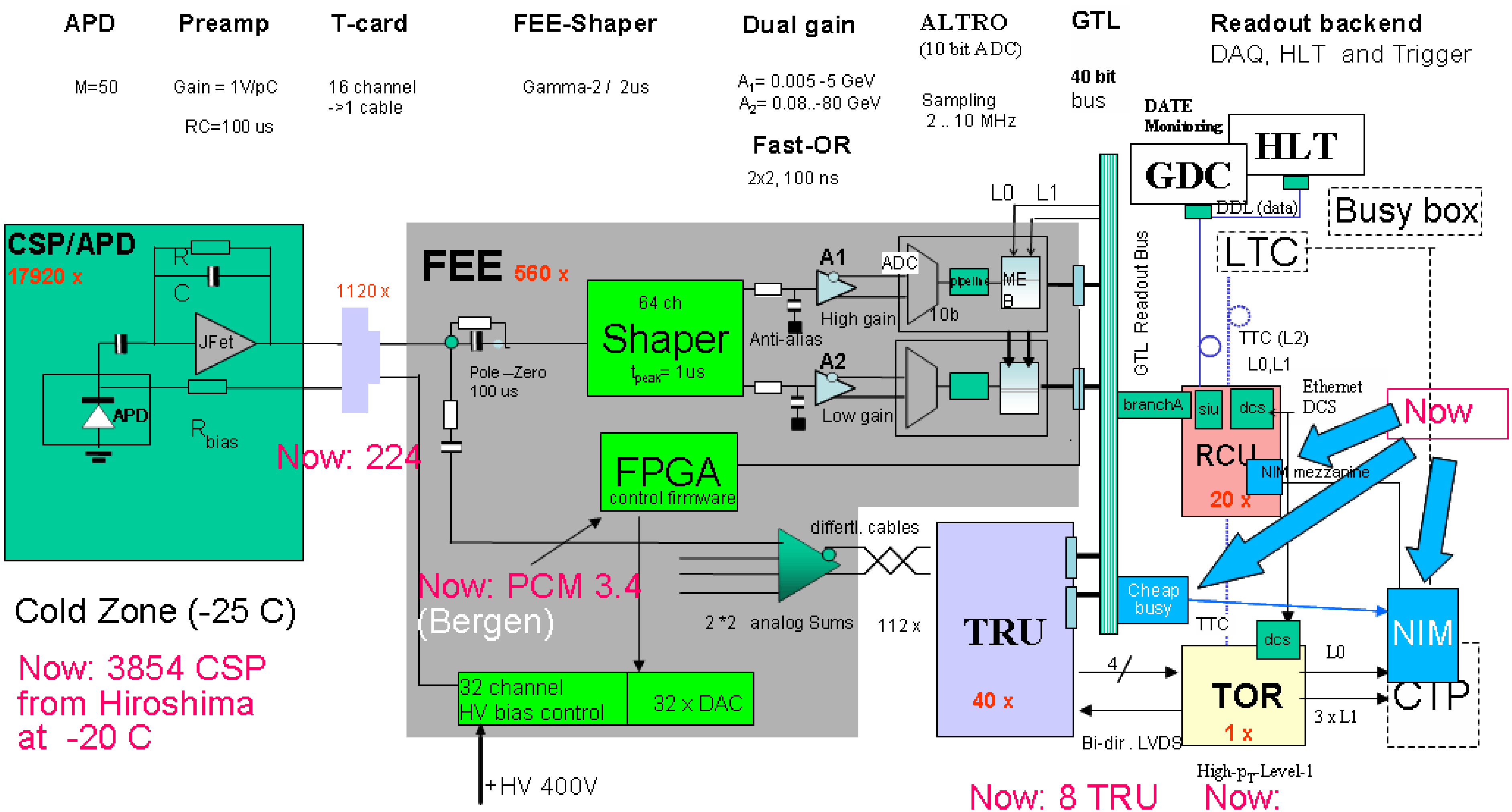




- **The PWO transmission is ~70% above 370 nm**
- **Light yield of PWO depends on temperature with coefficient of ~ -2%/ºC**

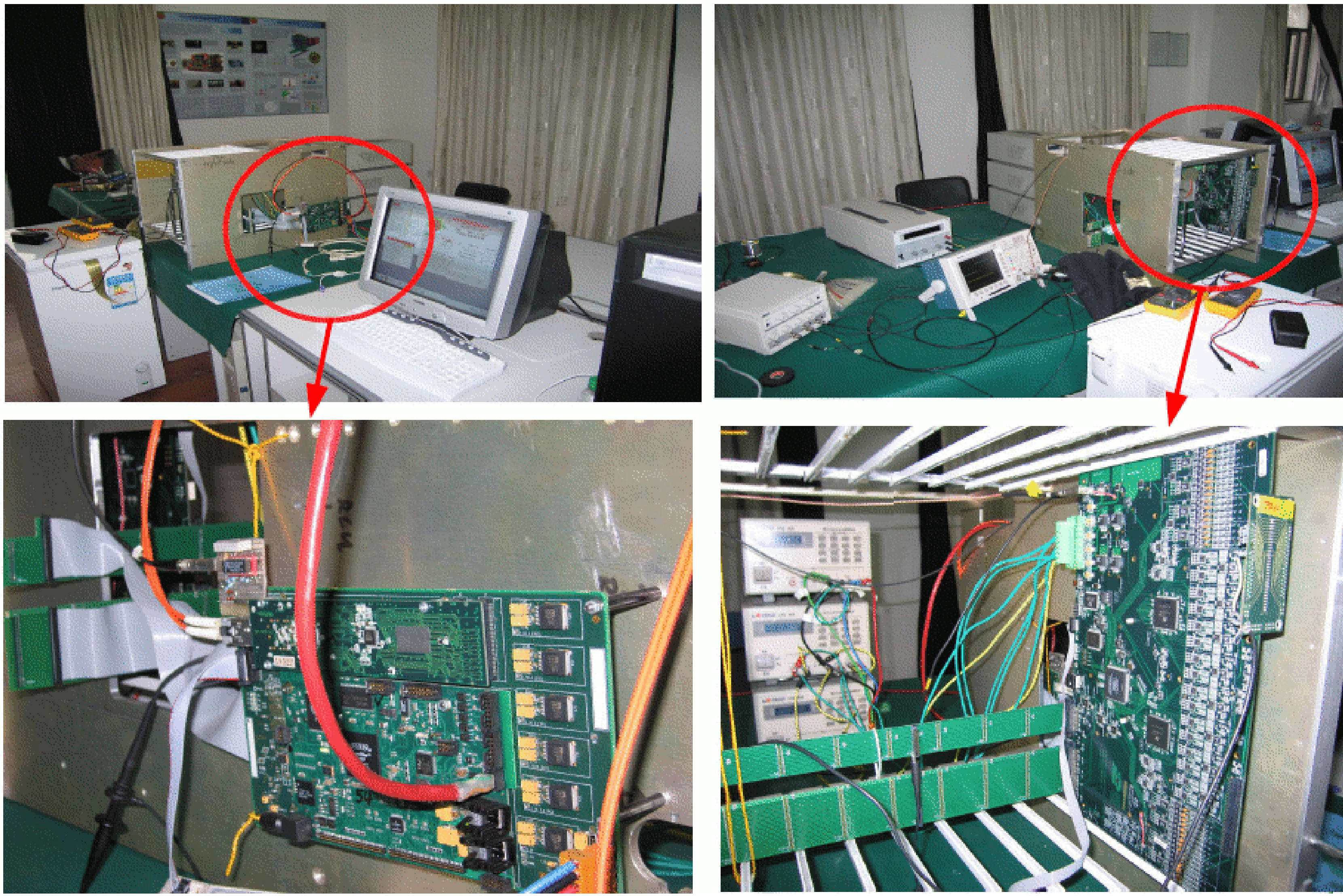
The ALICE PHOS Detector (III)

(Readout Chain)



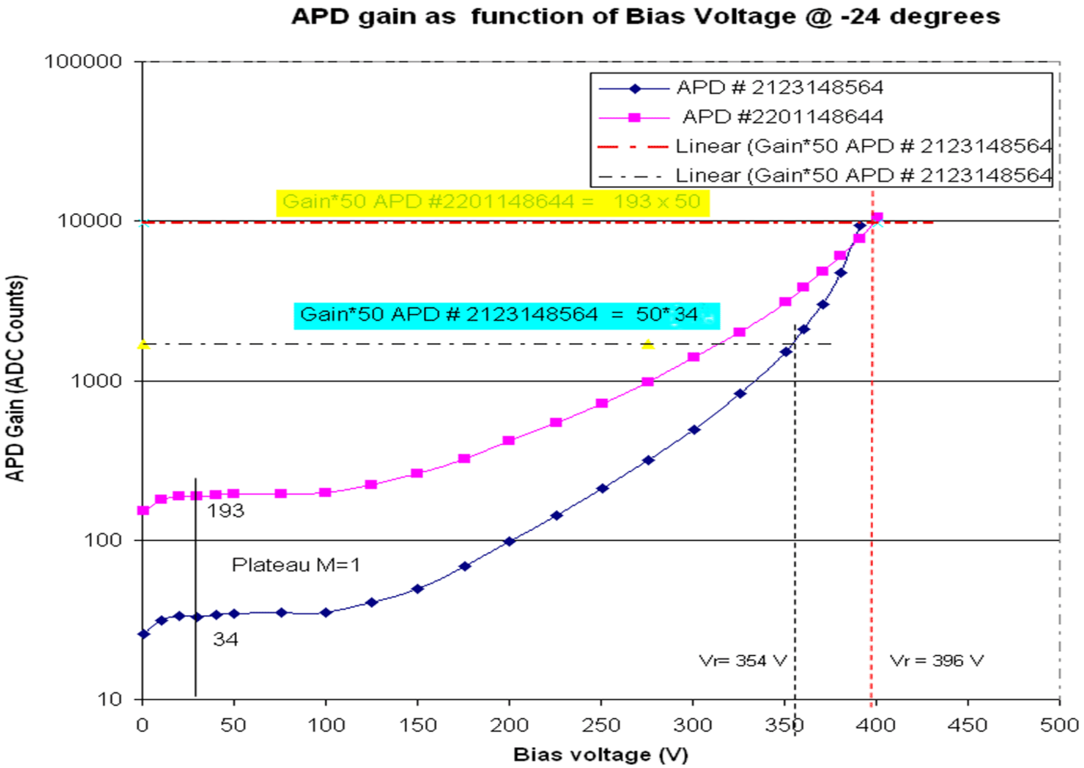
Test with LED or Step Pulser

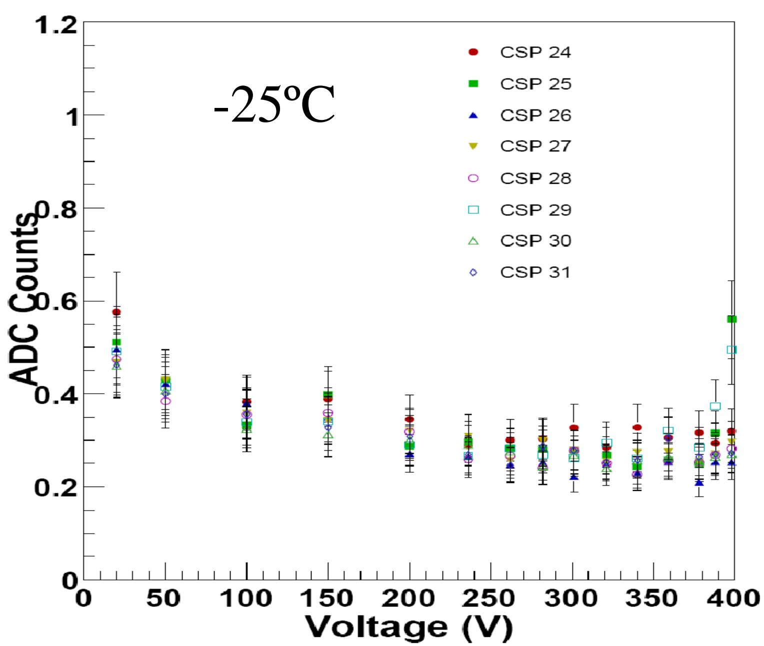
Test Bench at IOPP, Wuhan



APD

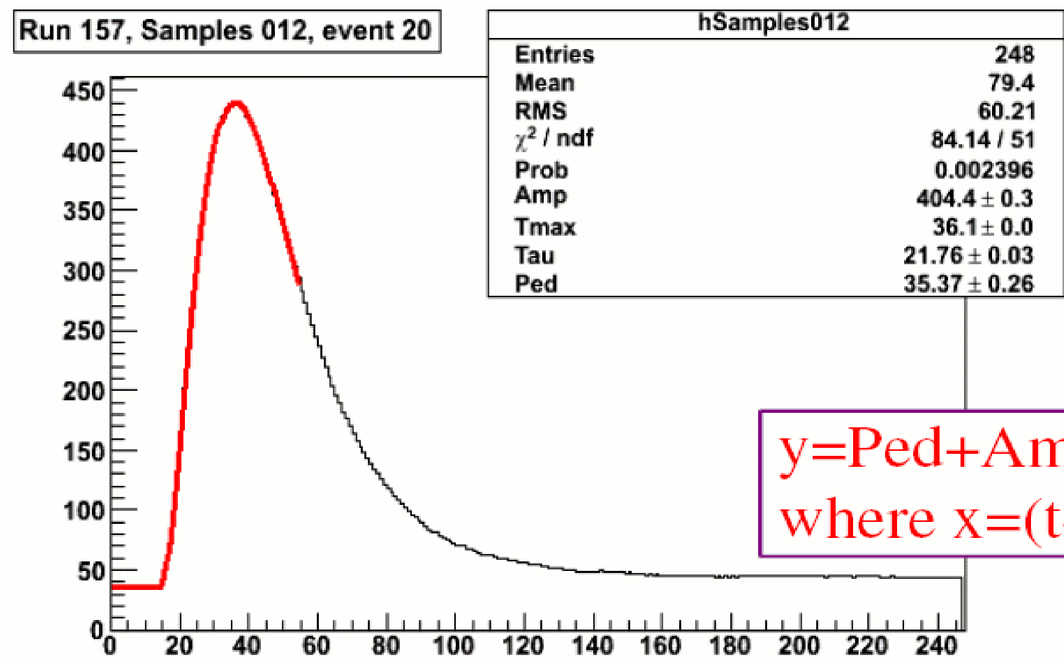
- APD capacitance decreases with bias voltage
- Dark current of APD increases with bias voltage
- Noise measurements with APD+CSP+FEE indicate a optimal bias voltage region around 300V

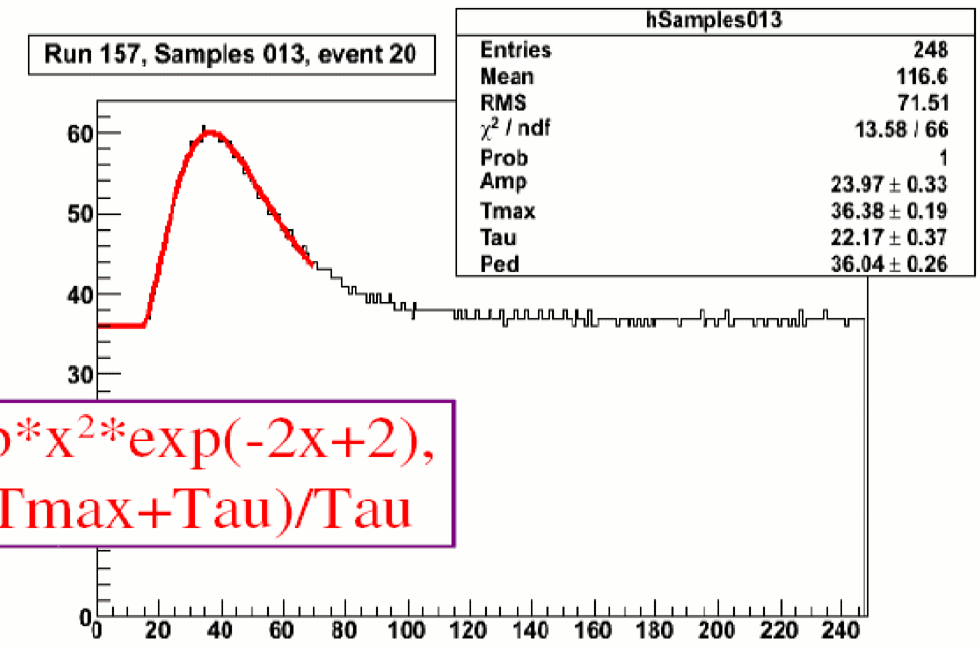




- APD gain increases with bias voltage when it operates in regular mode
- Apply constant LED light to measure the relative gain as function of bias voltage.
- Then from the plateau value for M=1 at ~25 V derive the absolute M=50 value of the bias voltage
- To equalize the APD gain, it requires to apply different bias voltage to individual APD

Front-End Electronics Card

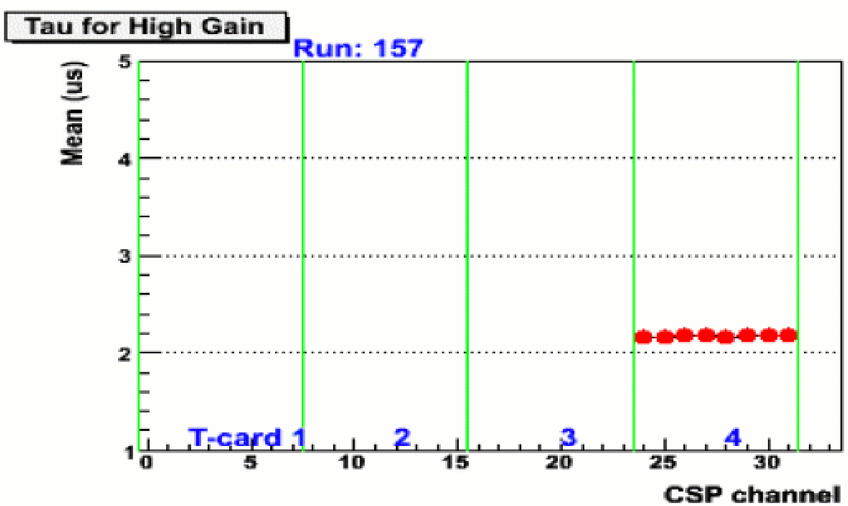


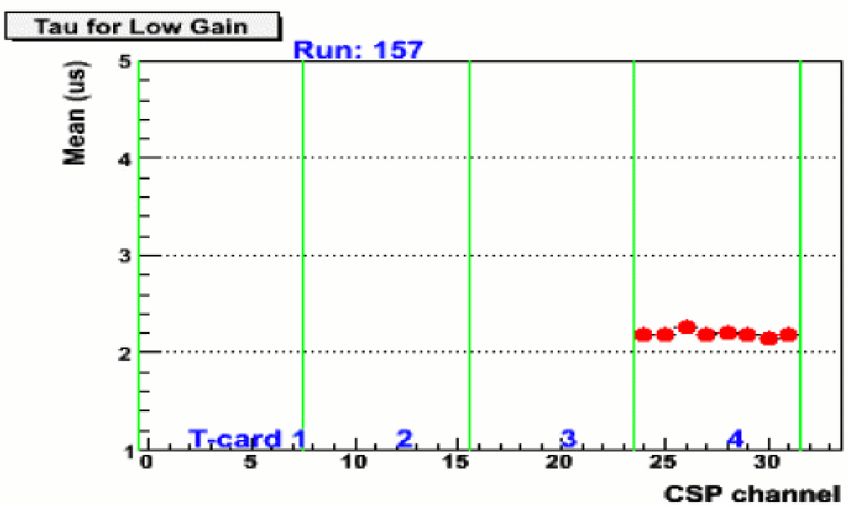


y=Ped+Amp*x^2*exp(-2x+2),
where x=(t-Tmax+Tau)/Tau

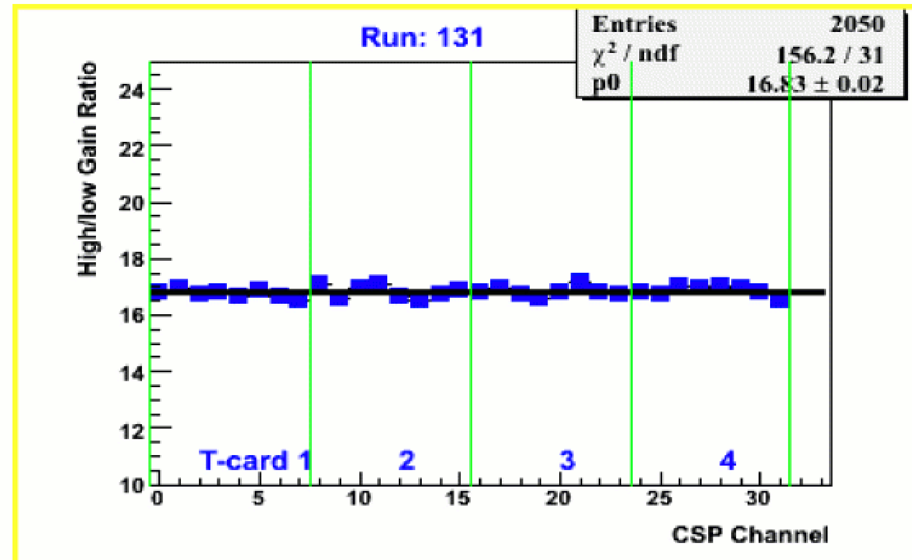
- For the second order implementation of shaper on the FEE card, the output pulse is shaped as Gamma-2 function.
- From the Gamma-2 fit, one can extract the peaking time τ, amplitude of the signal, time at peak position Tmax, pedestal and noise level.
- Comparing the amplitude from high gain (left) with that from low gain (right) channels, one can determine the amplification factor between high and low gain channels.

Front-End Electronics Card (II)





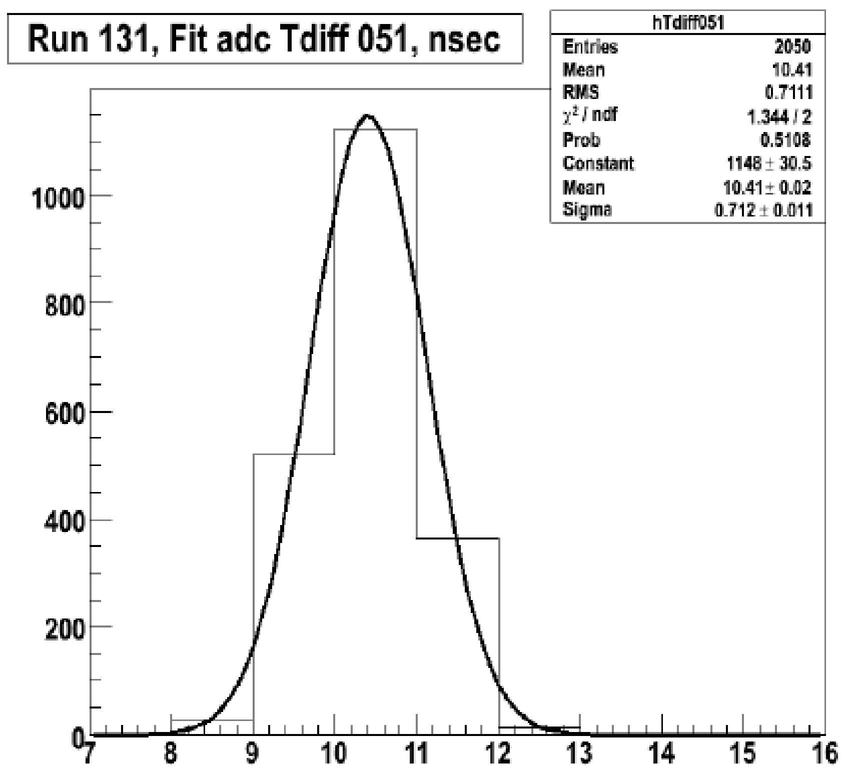
LED pulse to 8 channel of APD+CSP

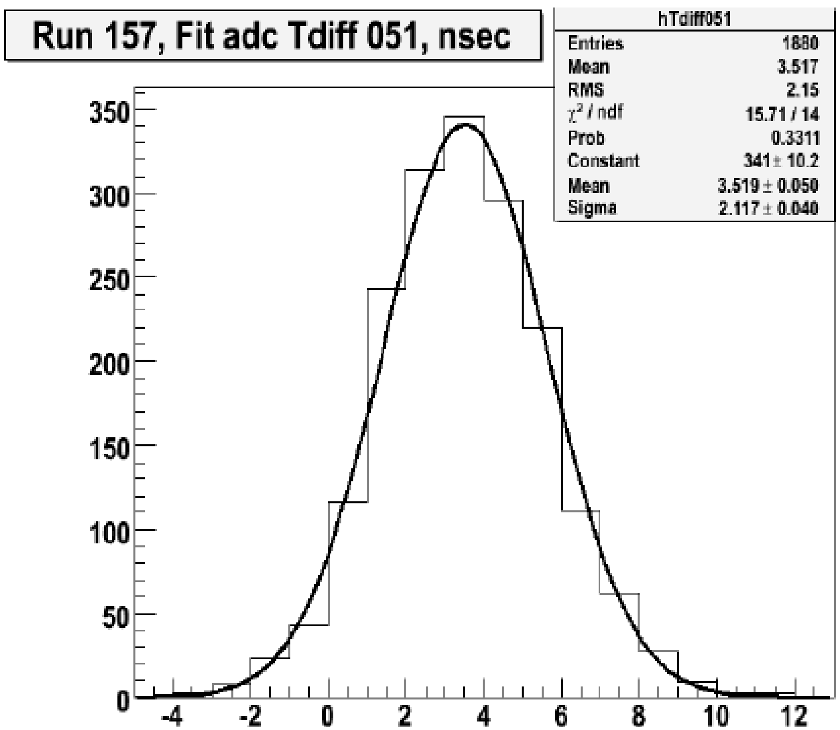


Step pulse to IPCB directly

In addition, measurements show that the average noise of PHOS with HV applied at -20 C is 0.53 ADC counts => 2.5 MeV/channel

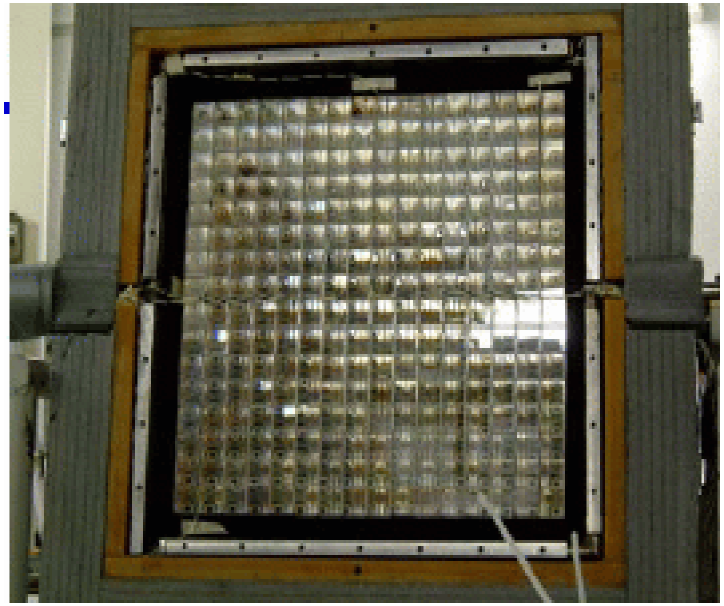
Front-End Electronics Card (III)



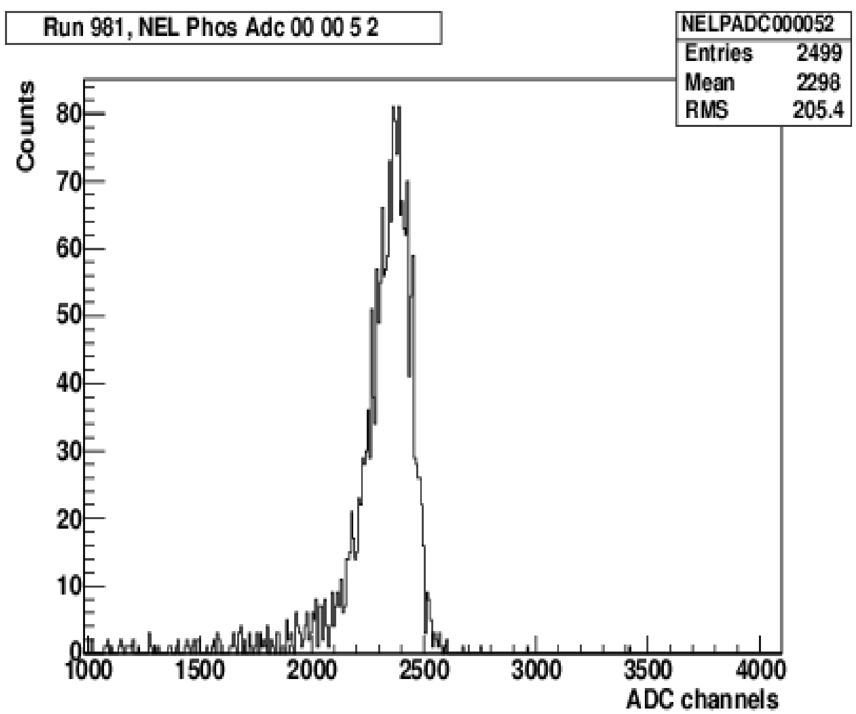


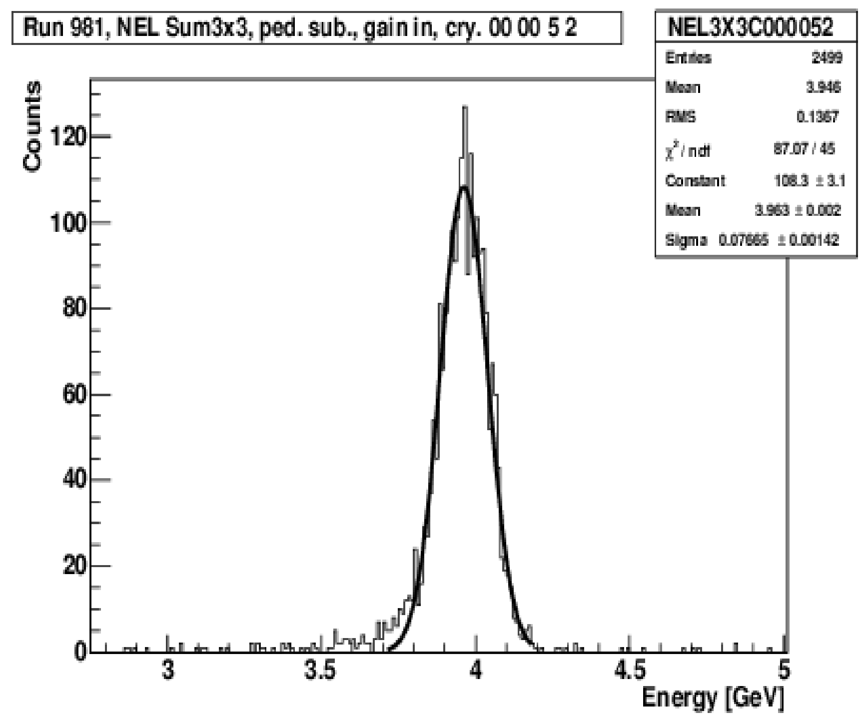
- The timing resolution is estimated by taking the time (Tmax) difference of two channels with a pulse signal equivalent to 2GeV photon. The timing resolution is sigma/sqrt(2).
- Left panel shows timing resolution measured with step pulse to IPCB directly; right panel shows timing resolution measured with LED pulse to APD+CSP.

Beam Test of the PHOS Prototype



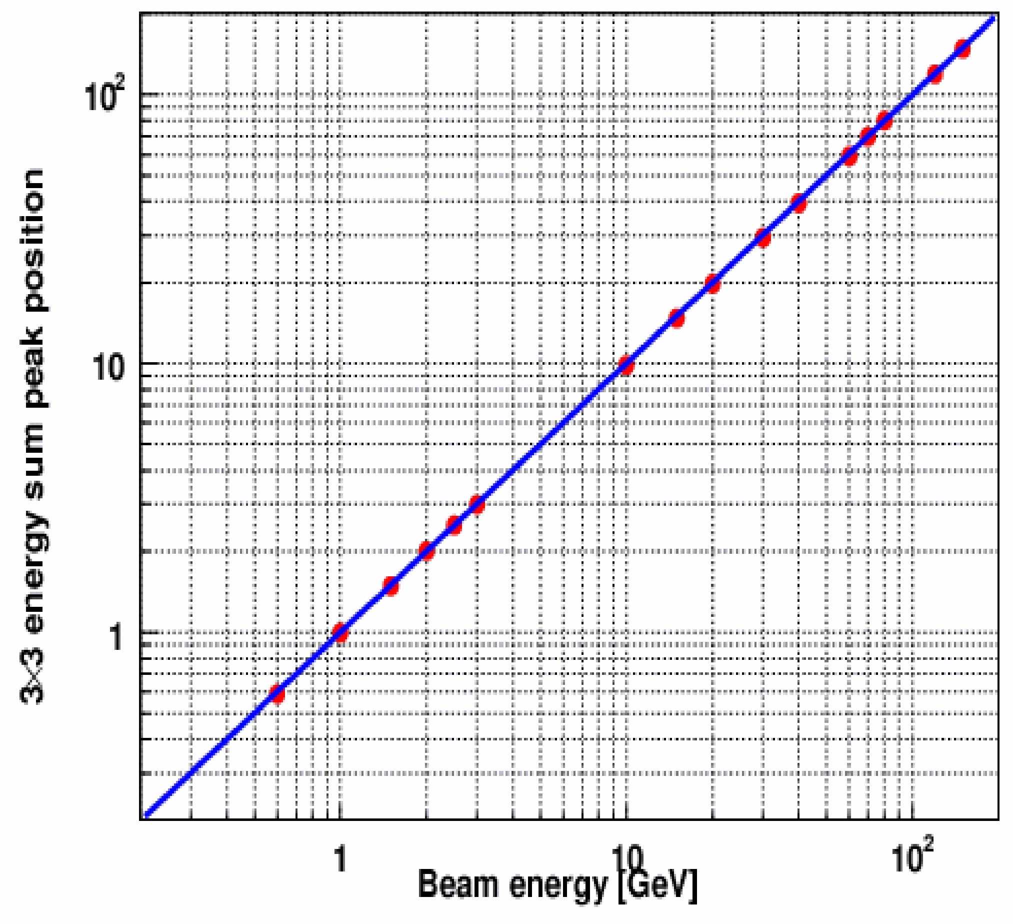
Energy Spectra





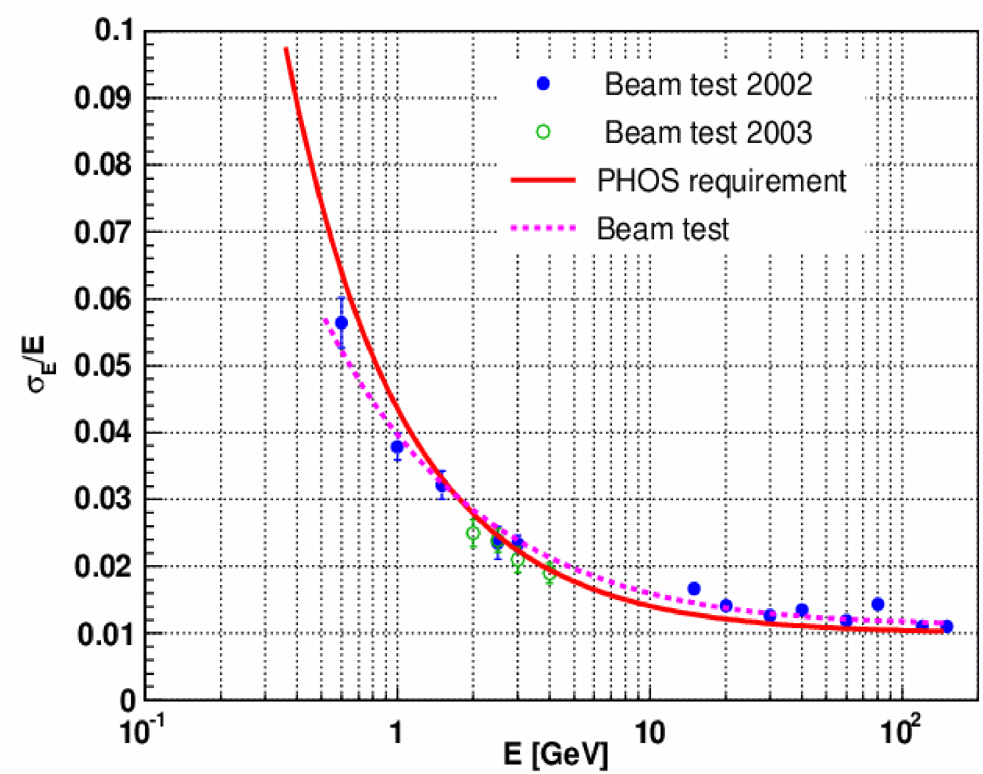
- Left: Spectrum from a single central detector of 18 cm long PWO crystal with 4 GeV/c electron beam
- Right: Spectrum from the central 3x3 array of detectors after pedestal subtraction and gain calibration

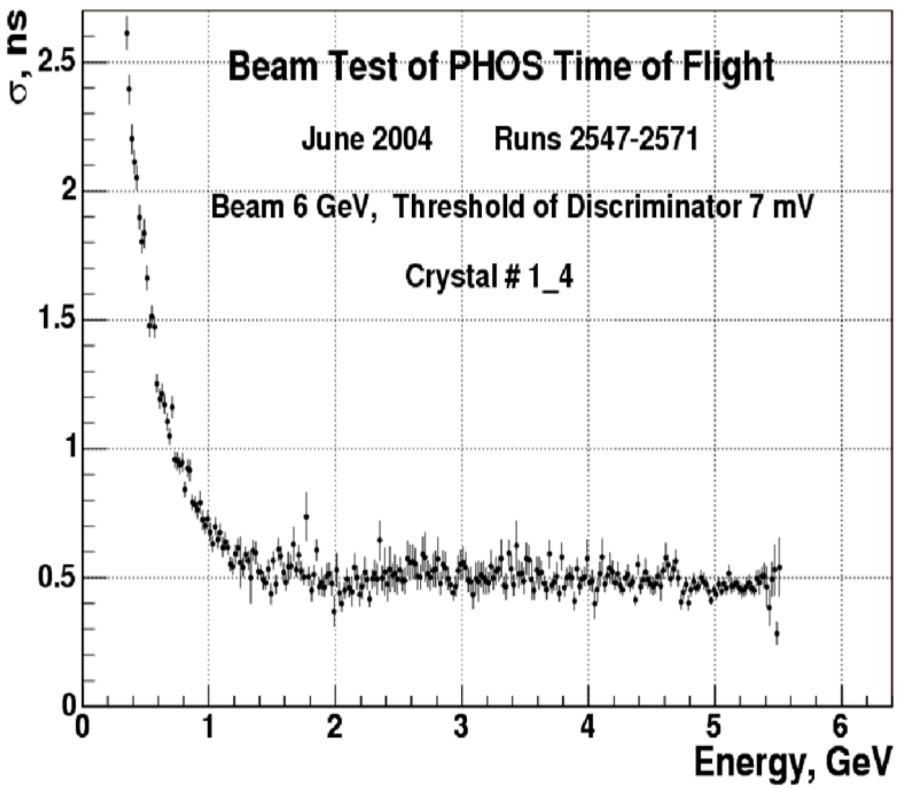
Linearity



- Fit a Gaussian to the measured spectrum after pedestal subtraction and gain calibration for 3x3 array of detectors
- The deviation from the linearity curve is less than 2%

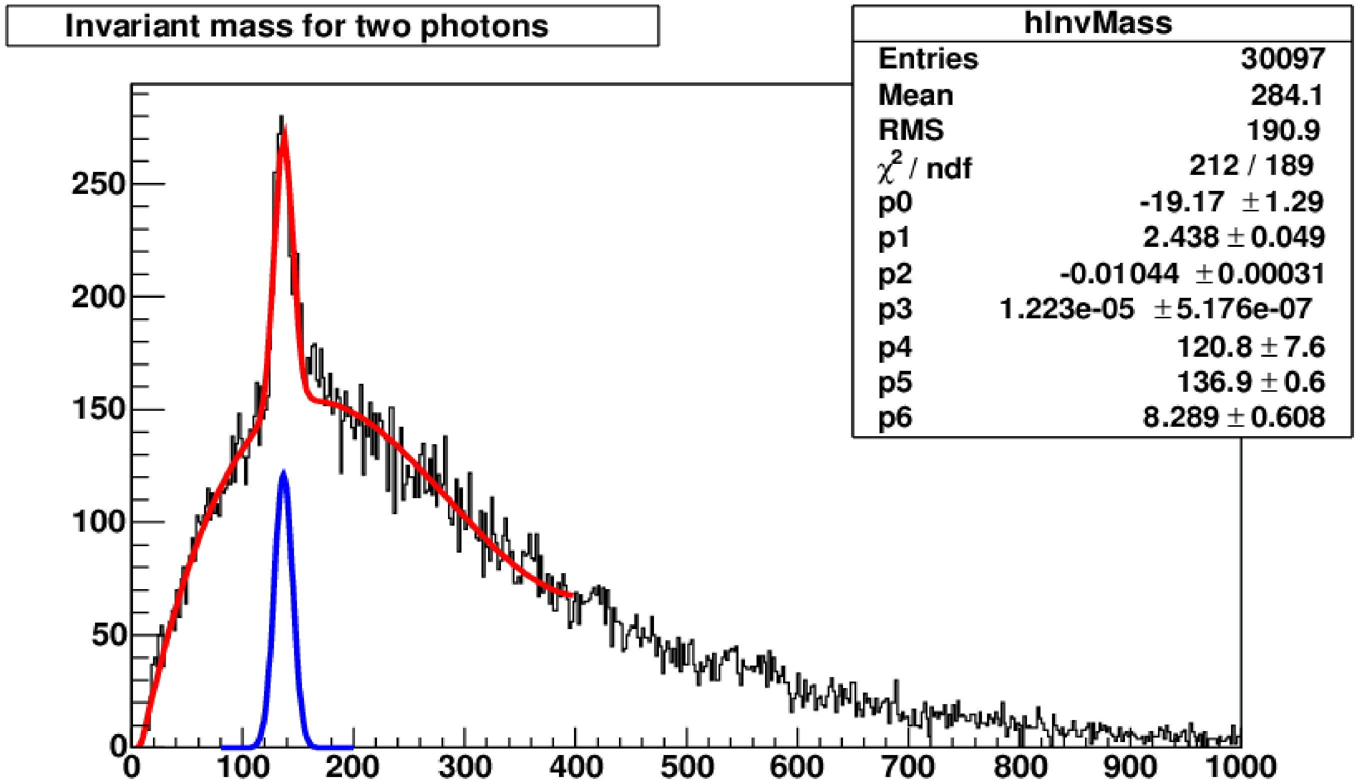
Energy and Timing Resolution





- **The requirement of energy resolution is fulfilled**
- **Measurements with TDC show the intrinsic timing resolution of PHOS is about 0.5 ns**

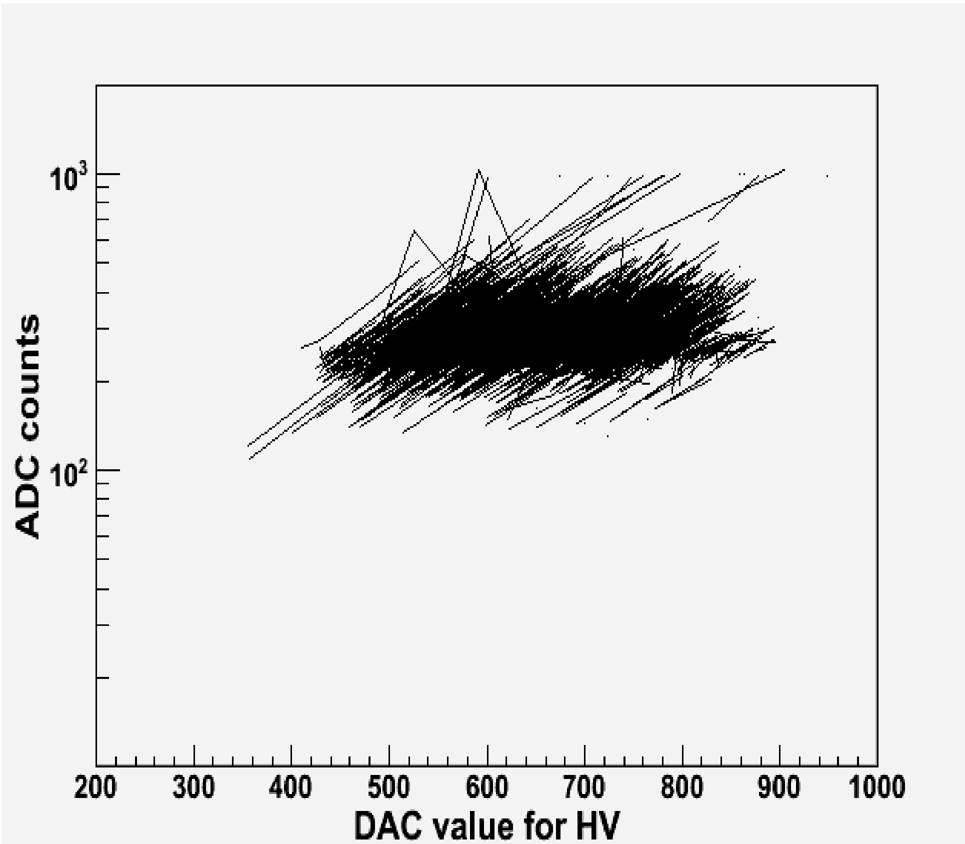
π^0 mass measurement



- 70 GeV/c $\pi^- + C \longrightarrow \gamma + \gamma + X$
- The target is located at a distance of 450 cm from the PHOS prototype
- The resulting resolution for neutral pion is around 6%

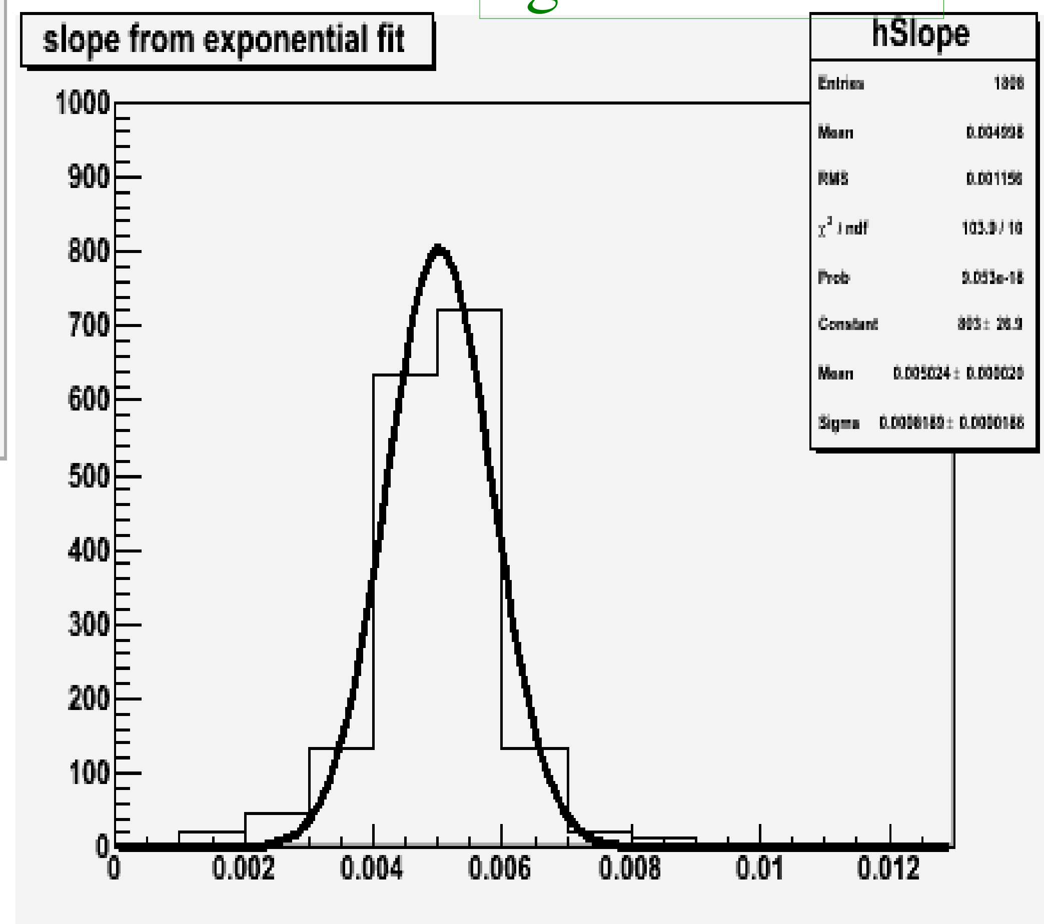
Beam Test of PHOS Module in 2006

Gain Equalization via HV

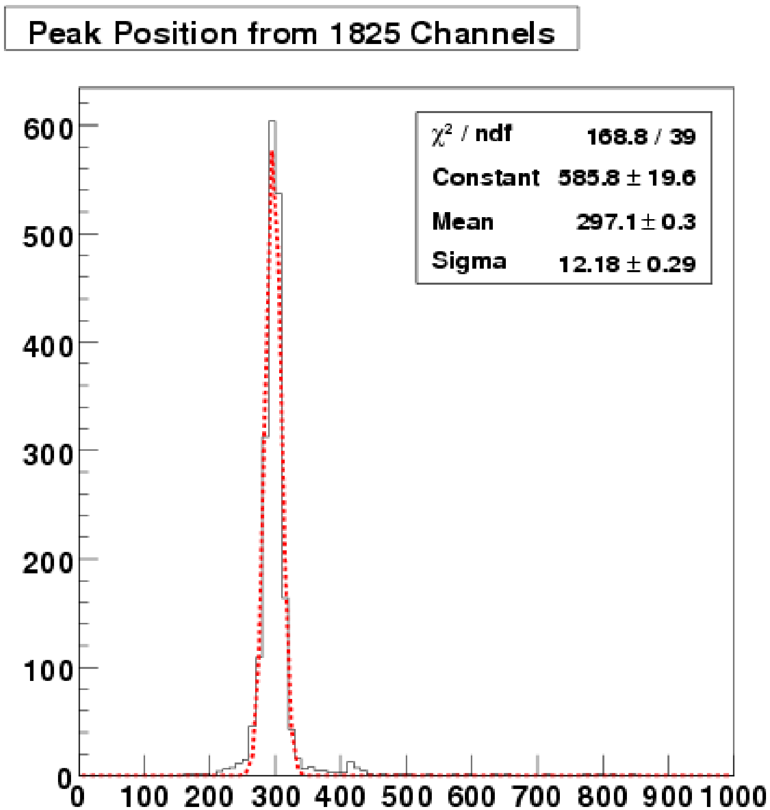


mean: 0.005

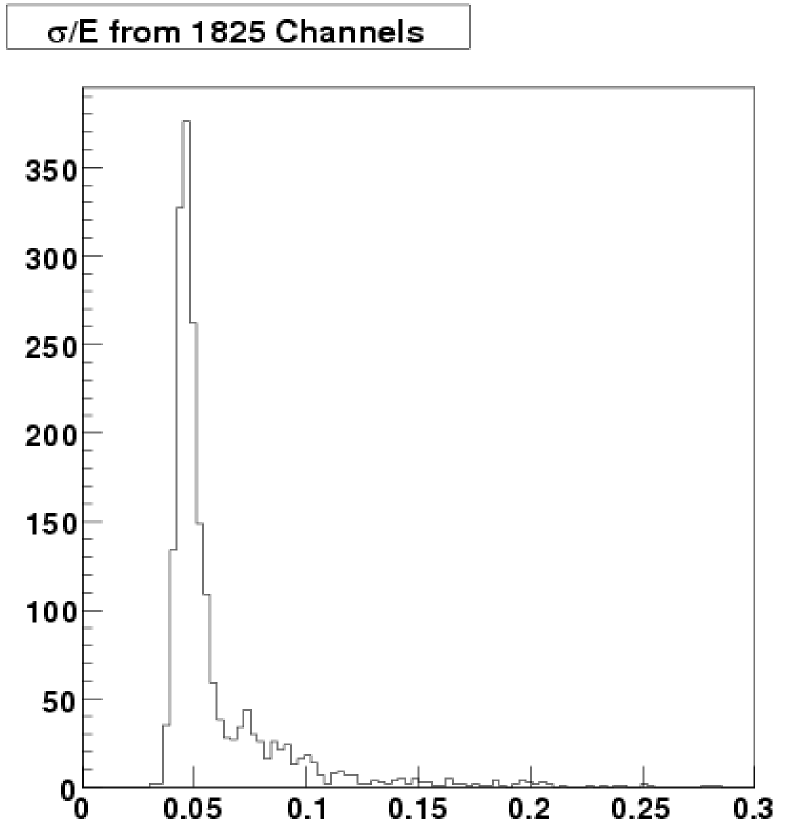
sigma: 0.0008



Gain Equalization via HV (cont'd)



Resolution peaks at 5% with 2 GeV electron beam.



4% gain balance were achieved by adjusting APD bias

Energy calibration via iteration

$$\sum_{i=0}^{8} g_i ADC_i = AdcCountsAt2GeV \qquad (1)$$

$$g_i * edgeValue_i = AdcCountsAt2GeV * factor, \qquad (2)$$

where $factor$ denotes the percentage of energy deposited in the crystal hit by electrons.

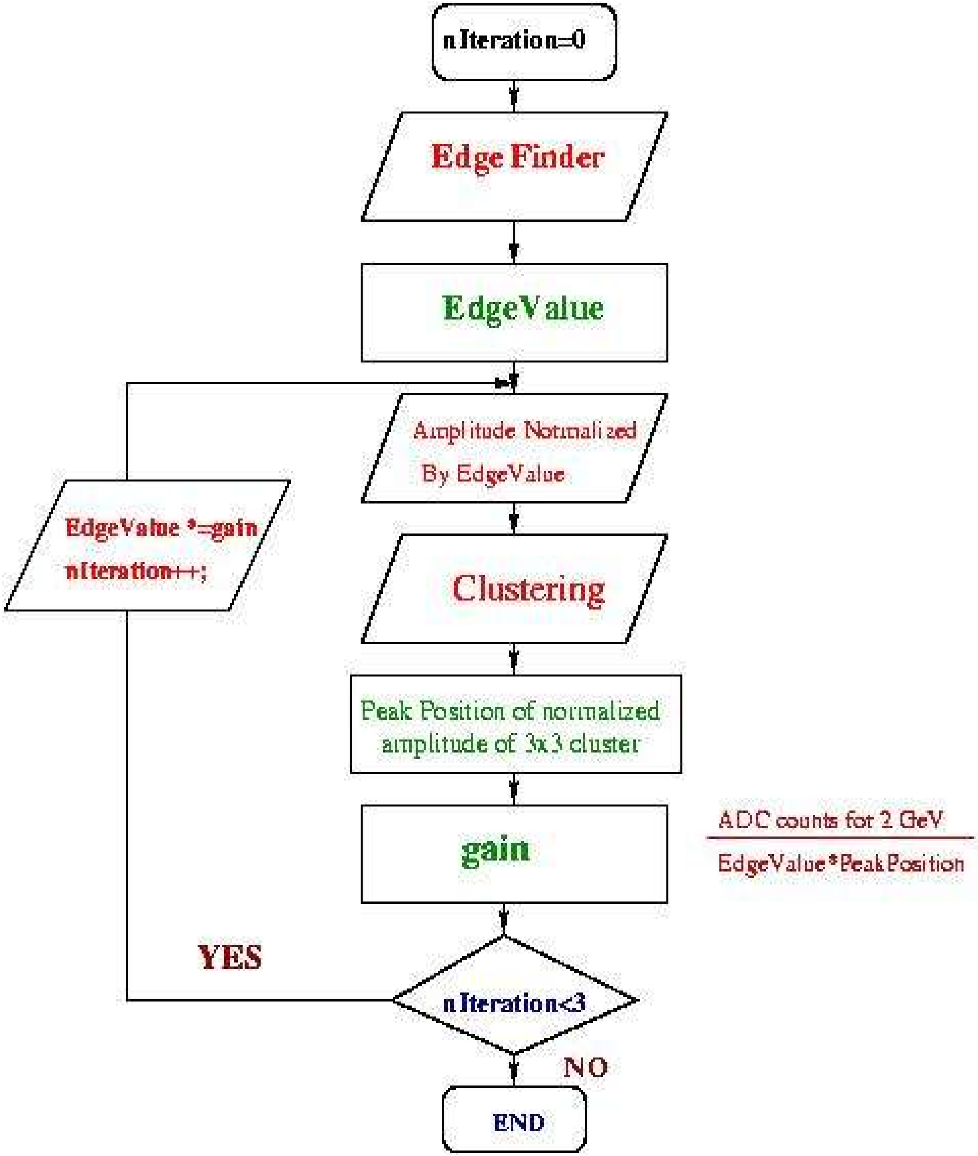
1 and 2 $\rightsquigarrow$

$$factor = \frac{1}{\sum_i \frac{ADC_i}{edgeValue_i}}, \qquad (3)$$

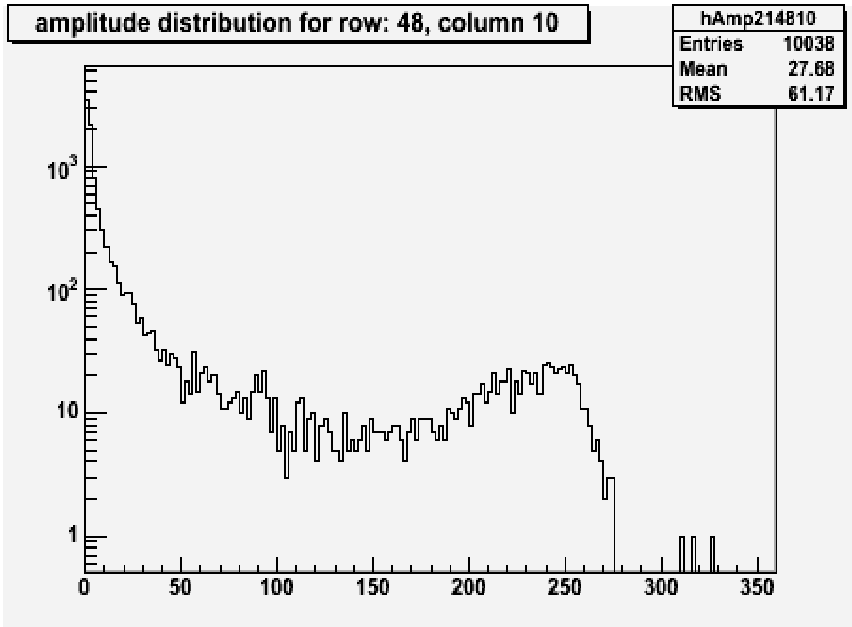
where $\sum_i \frac{ADC_i}{edgeValue_i}$ is normalized amplitude.

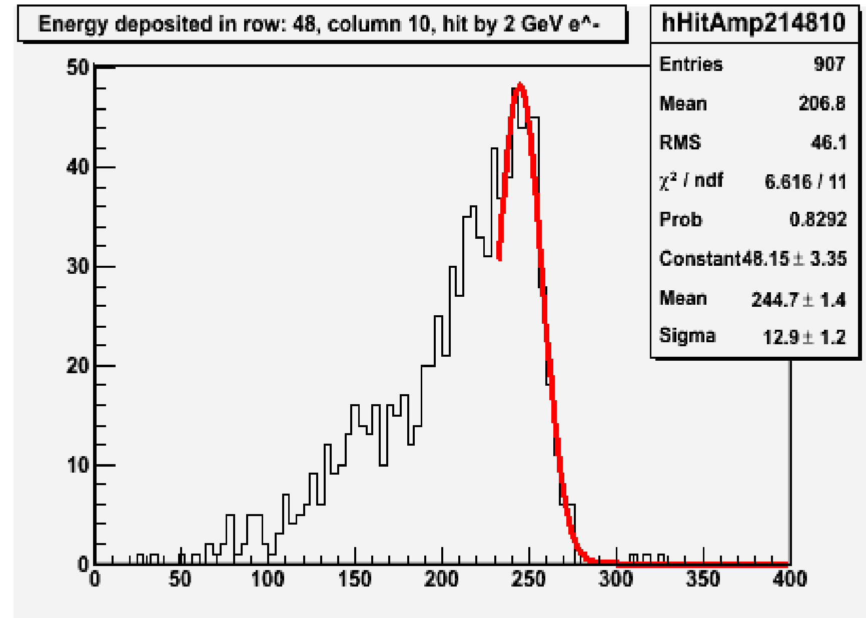
$\rightsquigarrow$

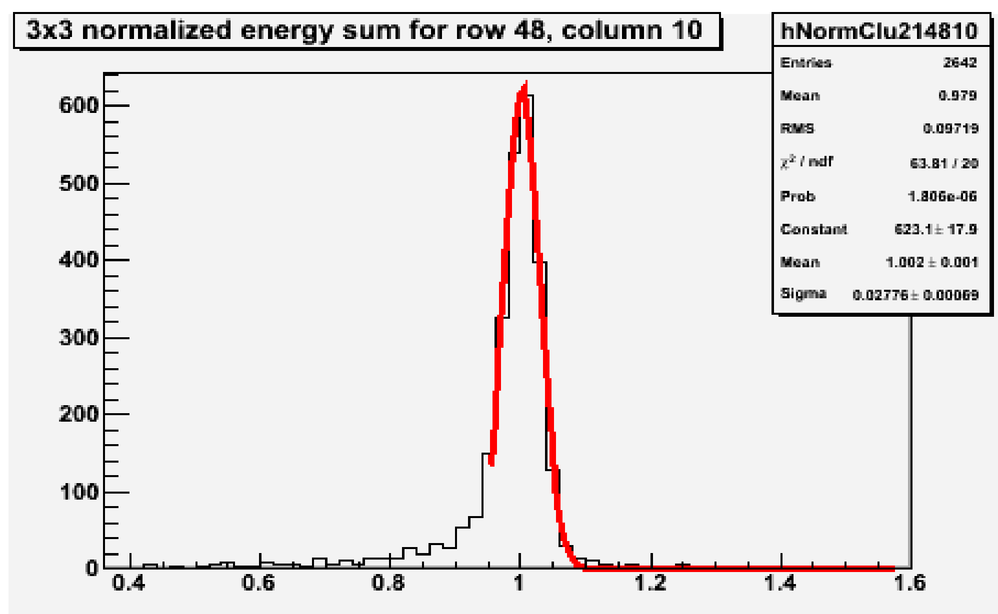
$$g_i = \frac{AdcCountsAt2GeV}{edgeValue_i * NormalizedClusterPeakPosition} \qquad (4)$$



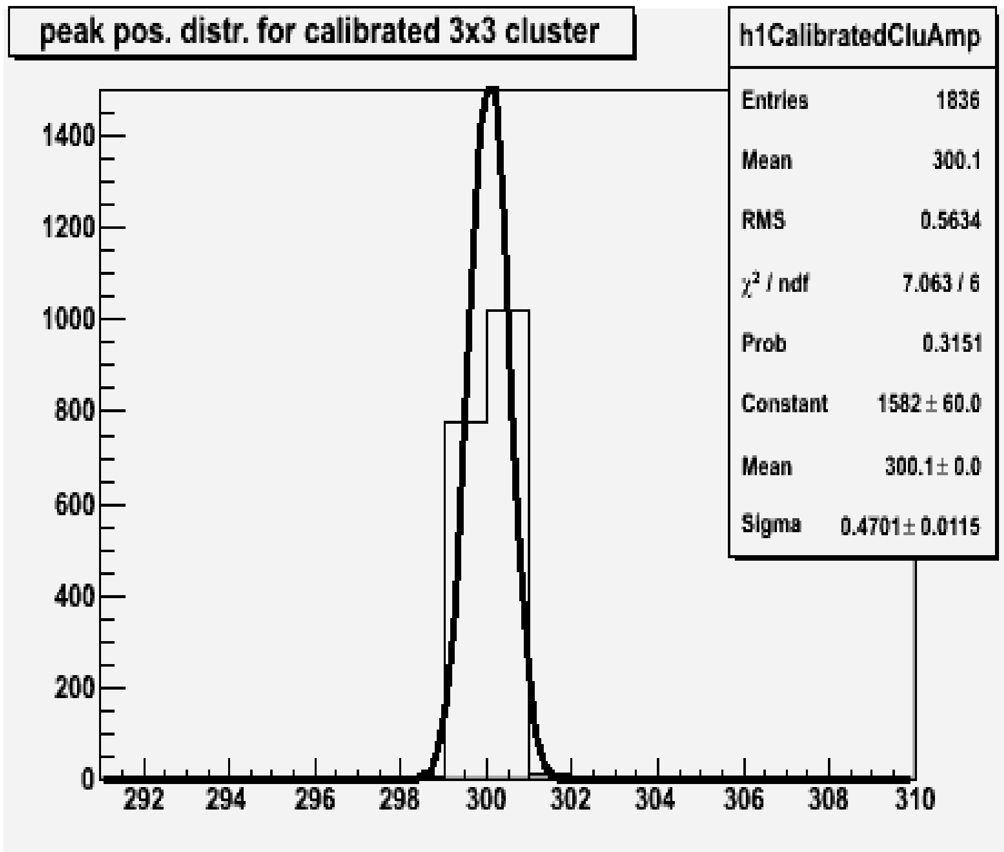
Energy calibration via iteration (cont'd)



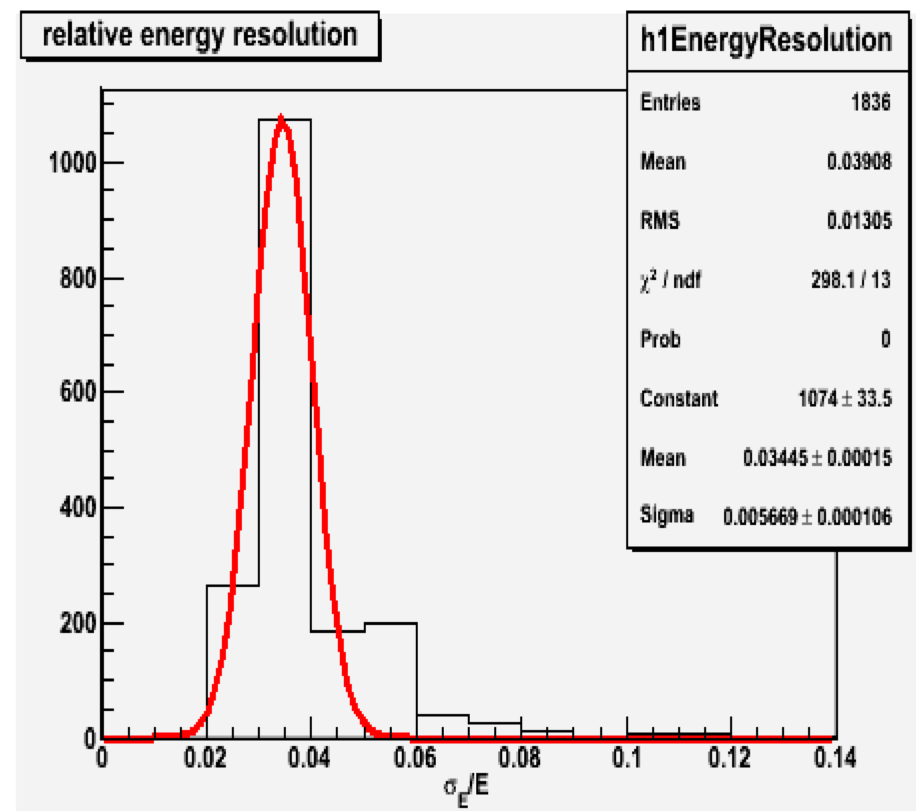




Energy calibration via iteration (cont'd)

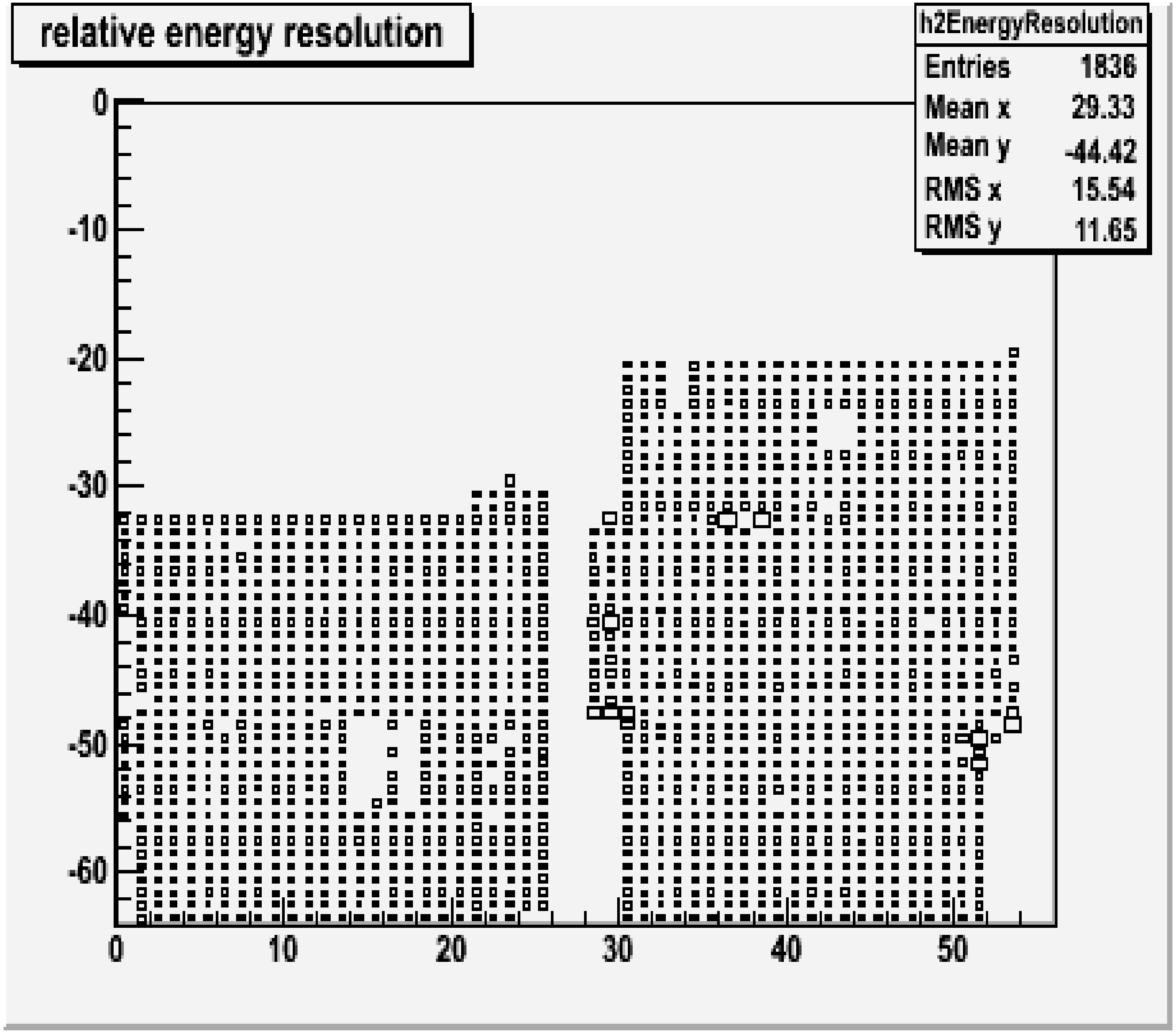


The mean of overall energy resolution from 3x3 clusters is 3.445% with a tail of worse resolution.

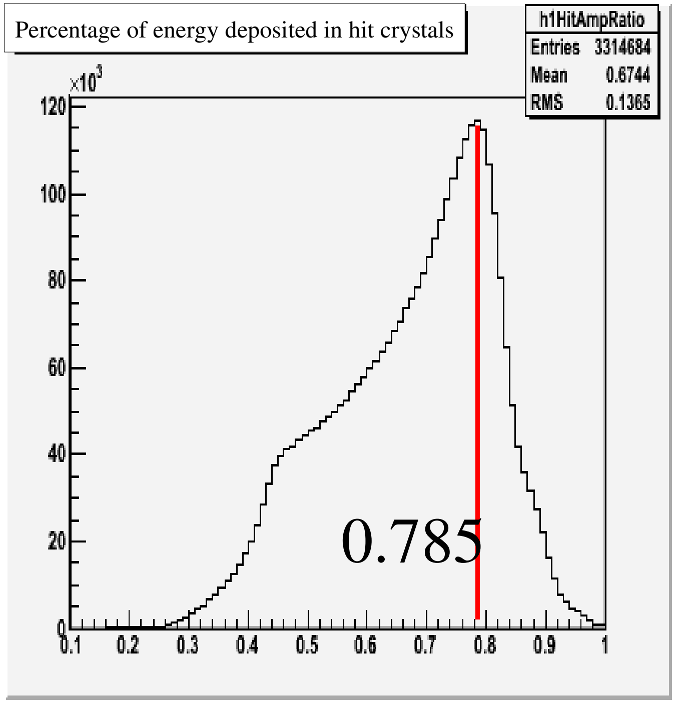


The response from difference channels can be equalized to very high precision after 3 iterations.

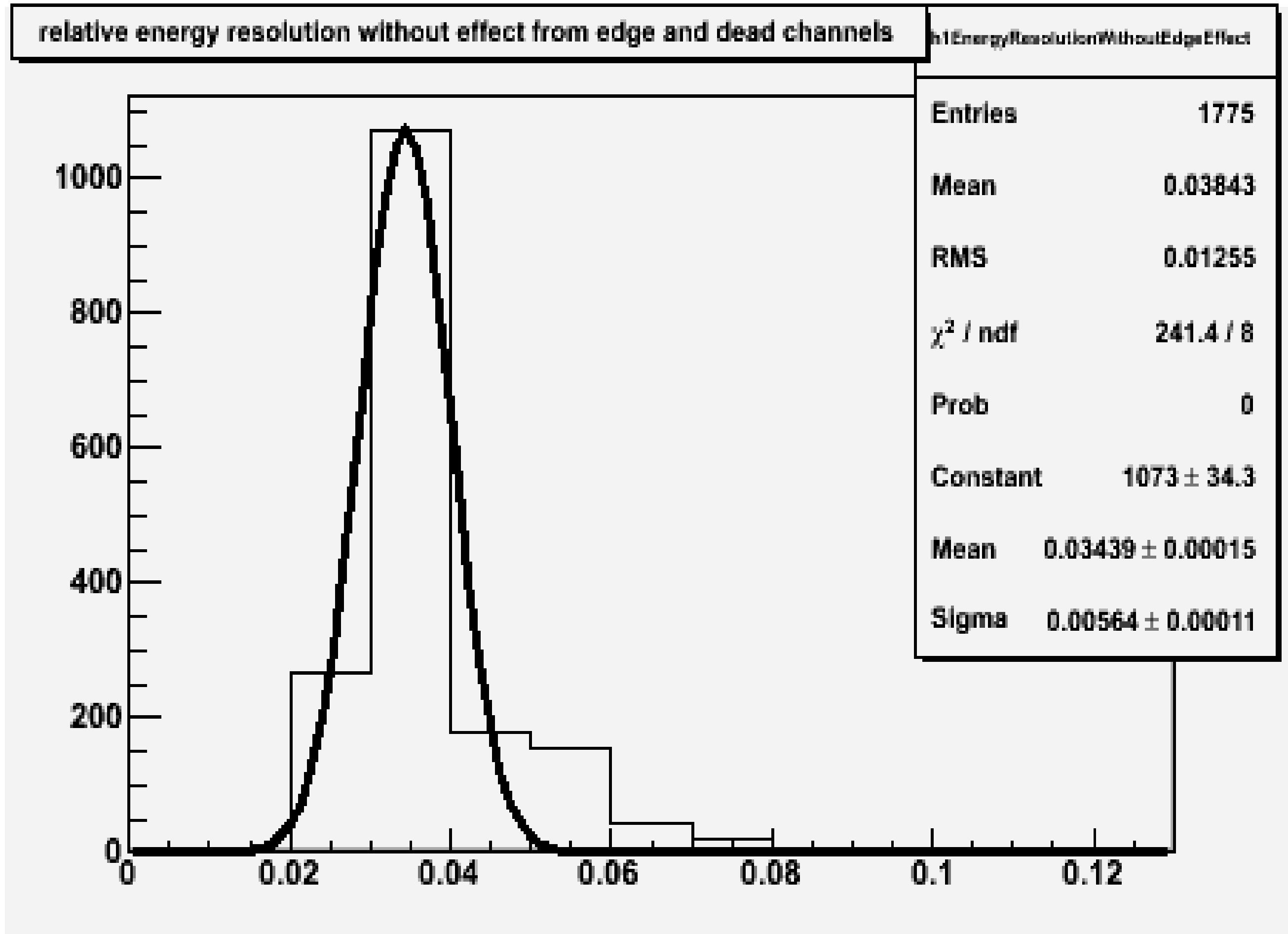
Energy calibration via iteration (cont'd)



Worse energy resolution at the edge of the module or near the dead channels.

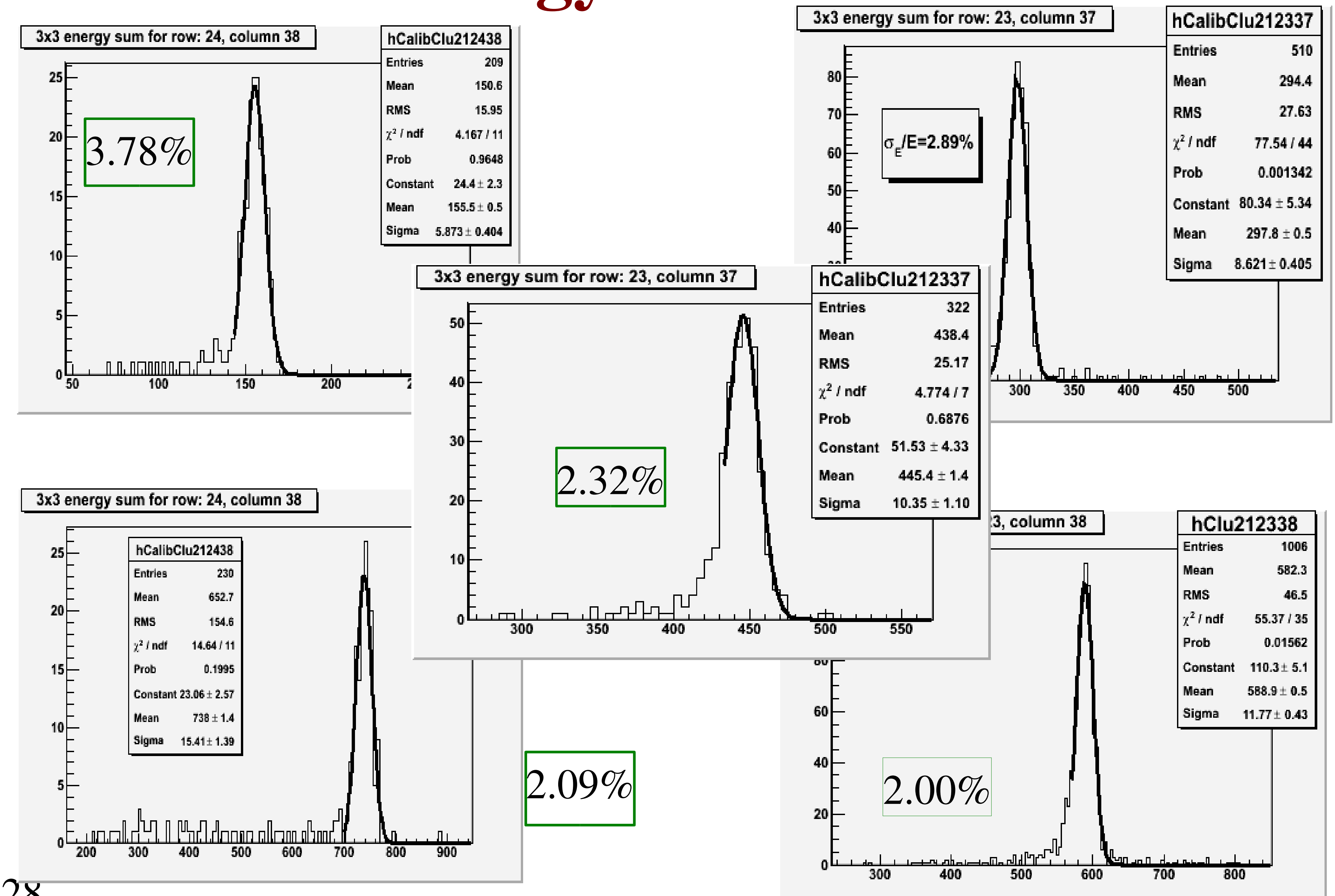


Energy calibration via iteration (cont'd)

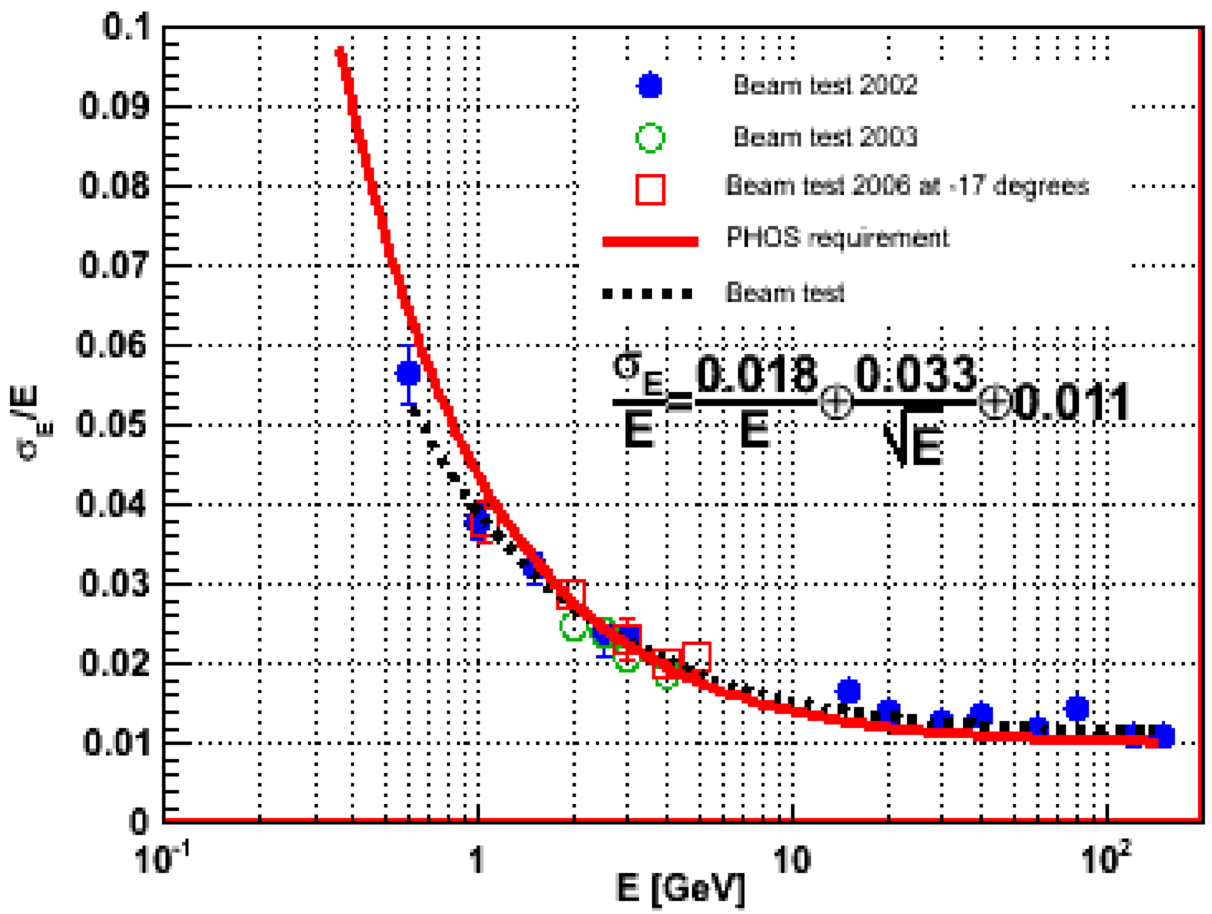


- The tail has not been completely eliminated but the mean value of the energy resolution is slightly improved.

Energy resolution

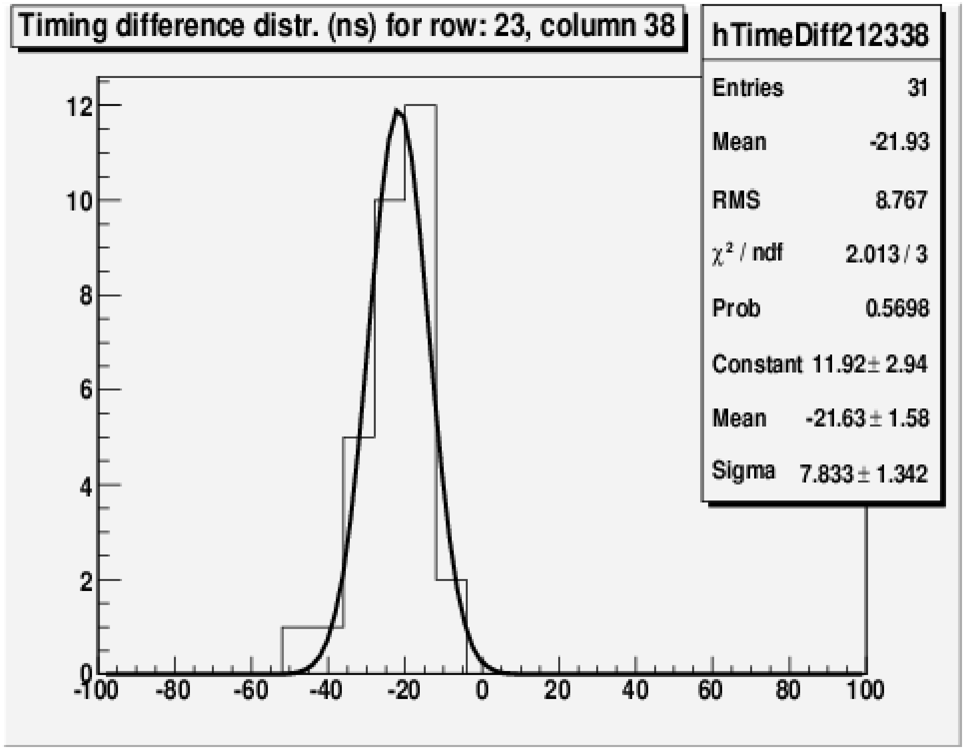


Energy resolution (cont'd)

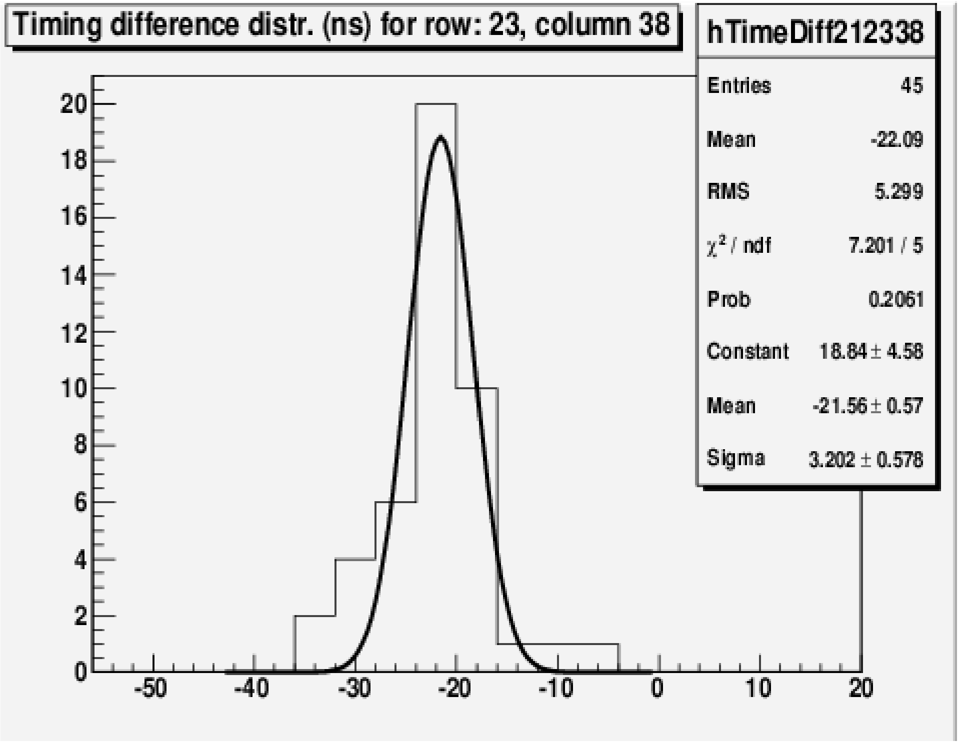


The energy resolution is quite good even though the temperature is only about –17 degrees.

Timing resolution

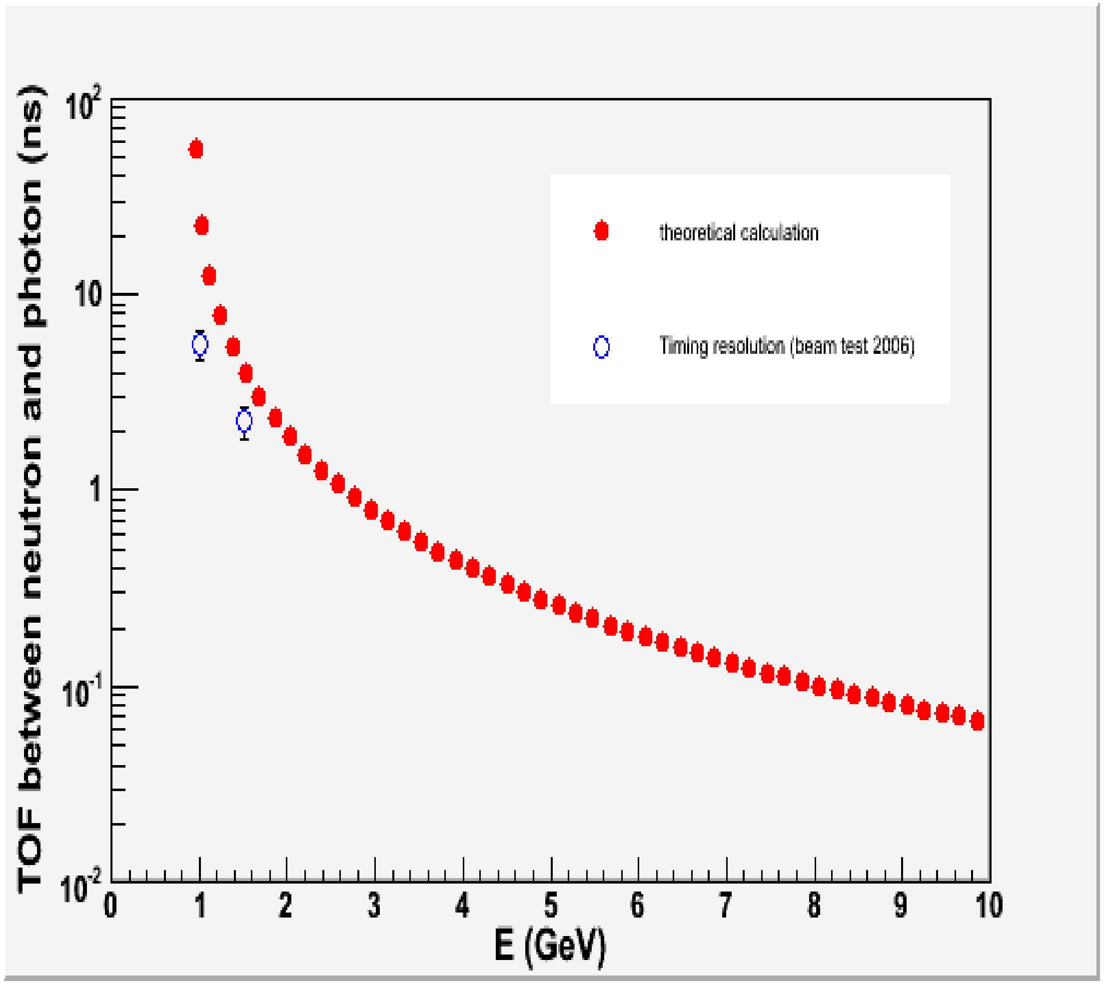


- 2GeV/c electron beam
- 120-130 ADC counts
- 5.54±0.95ns



- 3GeV/c electron beam
- 150-220 ADC counts
- 2.264±0.409ns

Timing resolution (cont'd)



- **Timing resolution is very marginal**
- **However, more ADC counts and lower noise at lower temperature should result in better timing resolution.**

Summary

- **At temperature of –17 ºC, by tuning bias voltage, gains of energy can be equalized to an accuracy of ca. 4%.**
- **With off-line calibration, the gains can be equalized to very high accuracy, the overall energy resolution of 3.44% at 2GeV/c has been achieved with a tail of worse resolution.**
- **With narrow electron beam, energy resolution from 1 to 5GeV/c is comparable to previous beam test results of PHOS prototype. One could expect better energy resolution at nominal temperature of –25 ºC .**
- **The timing resolution is marginal, however one can expect better result at lower temperature with higher amplitude of signal and lower noise level.**

Progress after 2006 Beam Test

- With updated RCU firmware and PHOS PCM firmware, most data corruption has been eliminated
- Loss of HV has been fixed
- With better design of GTL bus and FEE interface to T-Card, dead channels due to loose contact have been fixed
- Analysis on data from LED monitoring runs and cosmic runs is ongoing
- With implementation of BC firmware, TRU is now functioning and the PHOS L0/L1 trigger is under commissioning
- PHOS HLT is functioning and its performance is under investigation

Many thanks to my colleagues in PHOS group!

Special thanks to Dr. Hans Muller at CERN!