Calibration and Monitoring of the ZEUS Uranium Scintillator Calorimeter

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(On behalf of the ZEUS Collaboration)

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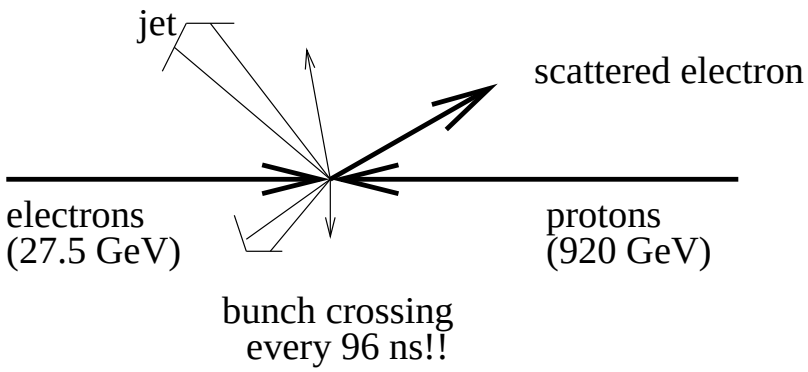
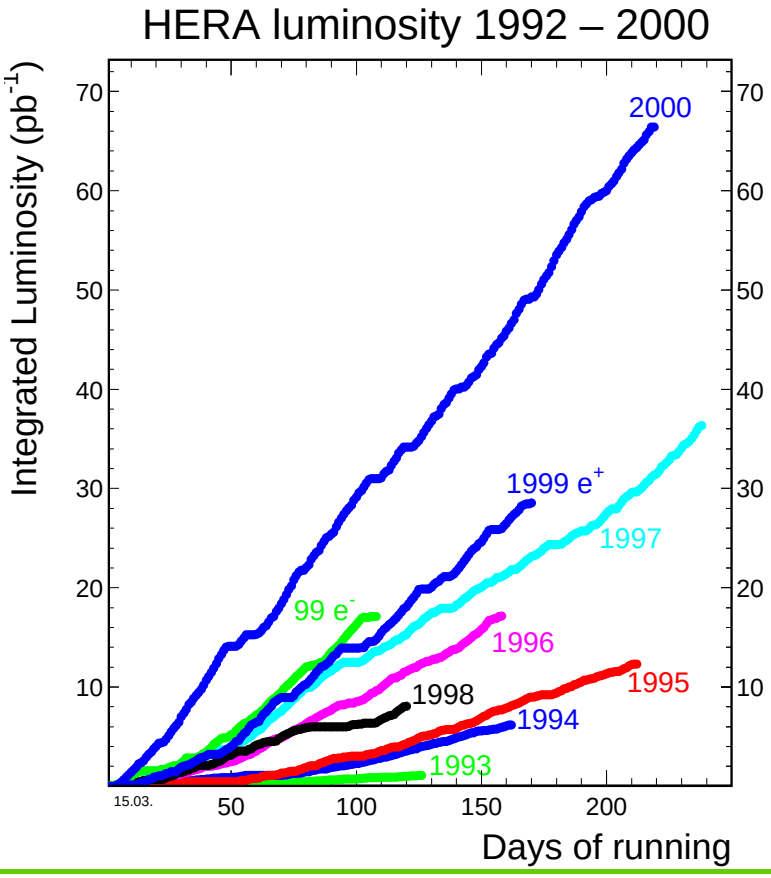
- HERA
- Calorimeter Characteristics
- Calibration Method
  - Uranium Signal
  - Electronics
- Monitoring
- Summary

HERA

- Hadron Electron Ring Accelerator (HERA) at DESY, Hamburg, Germany
- 920 GeV proton - 27.5 Gev electron collider
- Bunch crossing every 96 ns



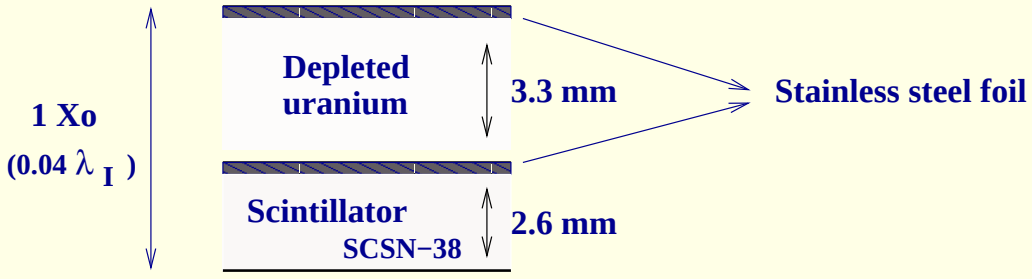


Calorimeter Characteristics

- Requirements
  - Provide high energy and time resolution

    $\Rightarrow$ Jet measurement, background suppression, ...
  - Measure the position of the scattered electron (DIS process)
  - Uniformity
  - Stability
  - Fast response (bunch crossing at 10 MHz)
- Design
  - Sampling Calorimeter

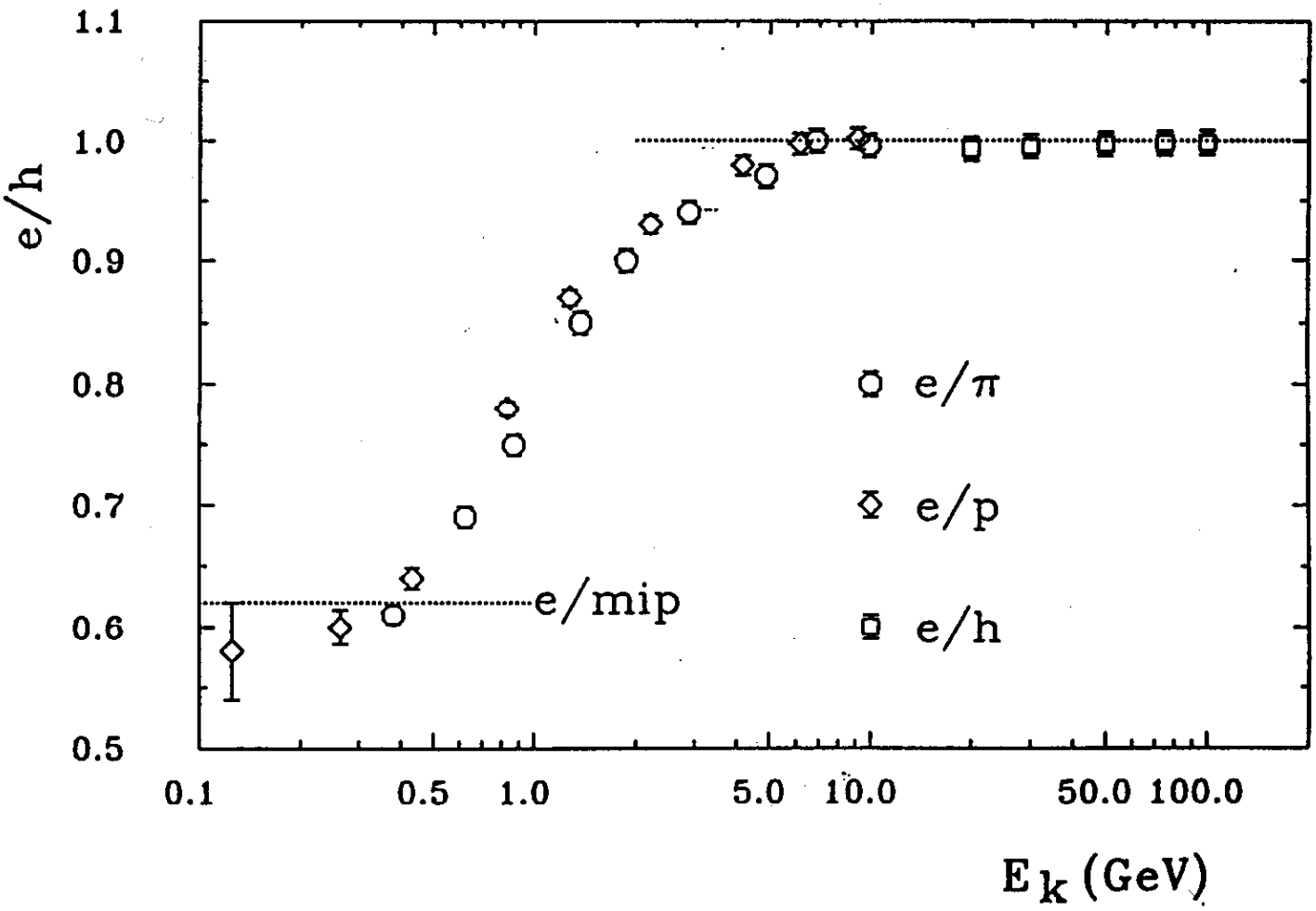
    $\Rightarrow$ Uranium-Scintillator Sandwich



Calorimeter Characteristics

- Compensation concept

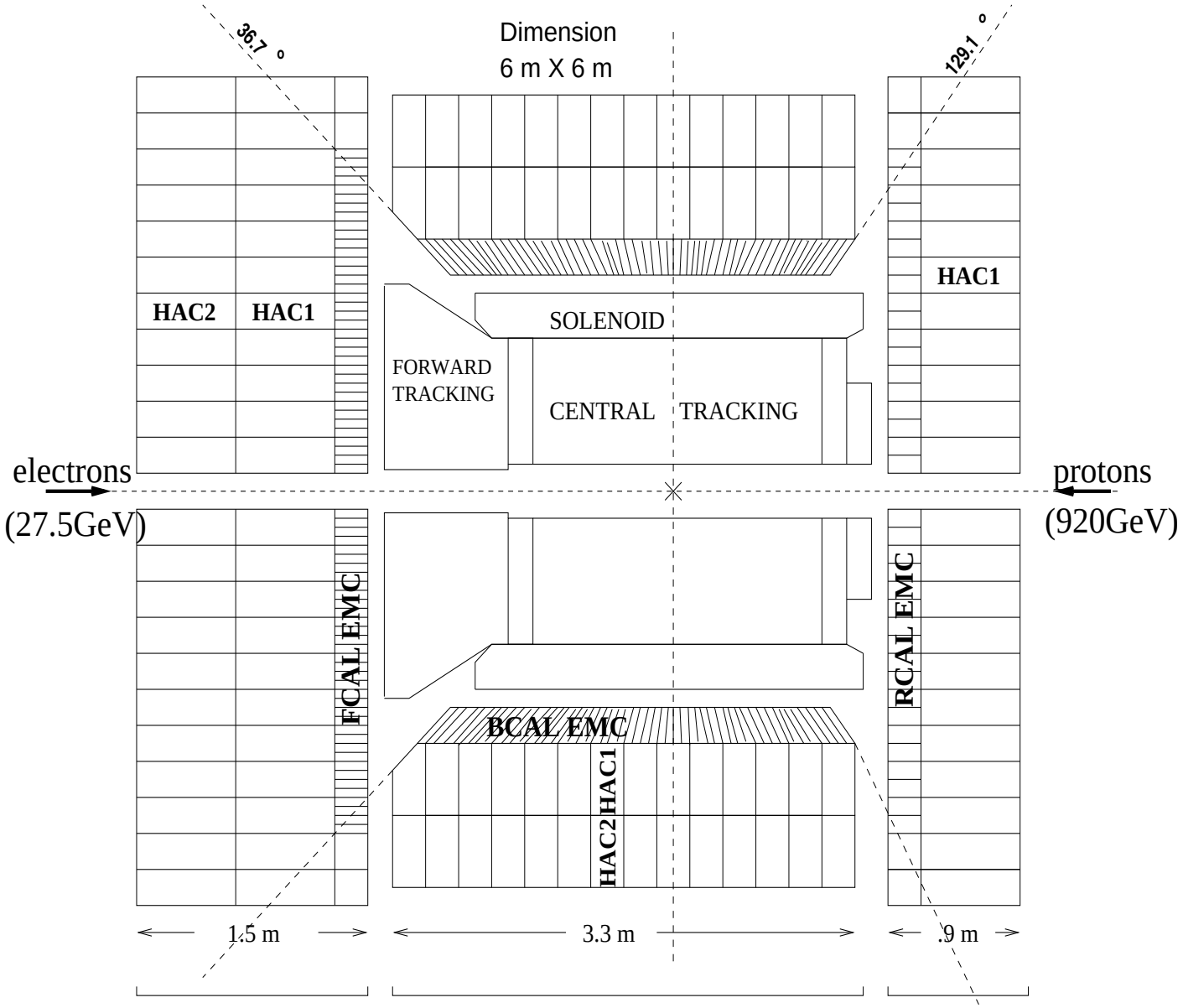
$\Rightarrow \frac{e}{h} = 1$



Calorimeter Characteristics

- 78 modules made up of Uranium-Scintillator plates
  - ⇒ Uniform 1 X_0 (0.04 λ_I) throughout the entire calorimeter
  - ⇒ 23 forward (proton direction) modules (FCAL), covering 2^o - 40^o
  - ⇒ 32 central barrel modules (BCAL), covering 37^o - 129^o
  - ⇒ 23 rear (electron direction) modules (RCAL), covering 128^o - 177^o
  - ⇒ Each module is subdivided in towers
  - ⇒ Each tower is segmented longitudinally in
    - Electromagnetic cell, 1.1 λ_I
    - hadronic cells
      - 6 λ_I in FCAL
      - 3 λ_I in RCAL
      - 4 λ_I in BCAL

Calorimeter Characteristics



FCAL ($7\lambda_I$)

HAC1,2 : $3.1\lambda_I$
Depth : 1.52 m

BCAL ($5\lambda_I$)

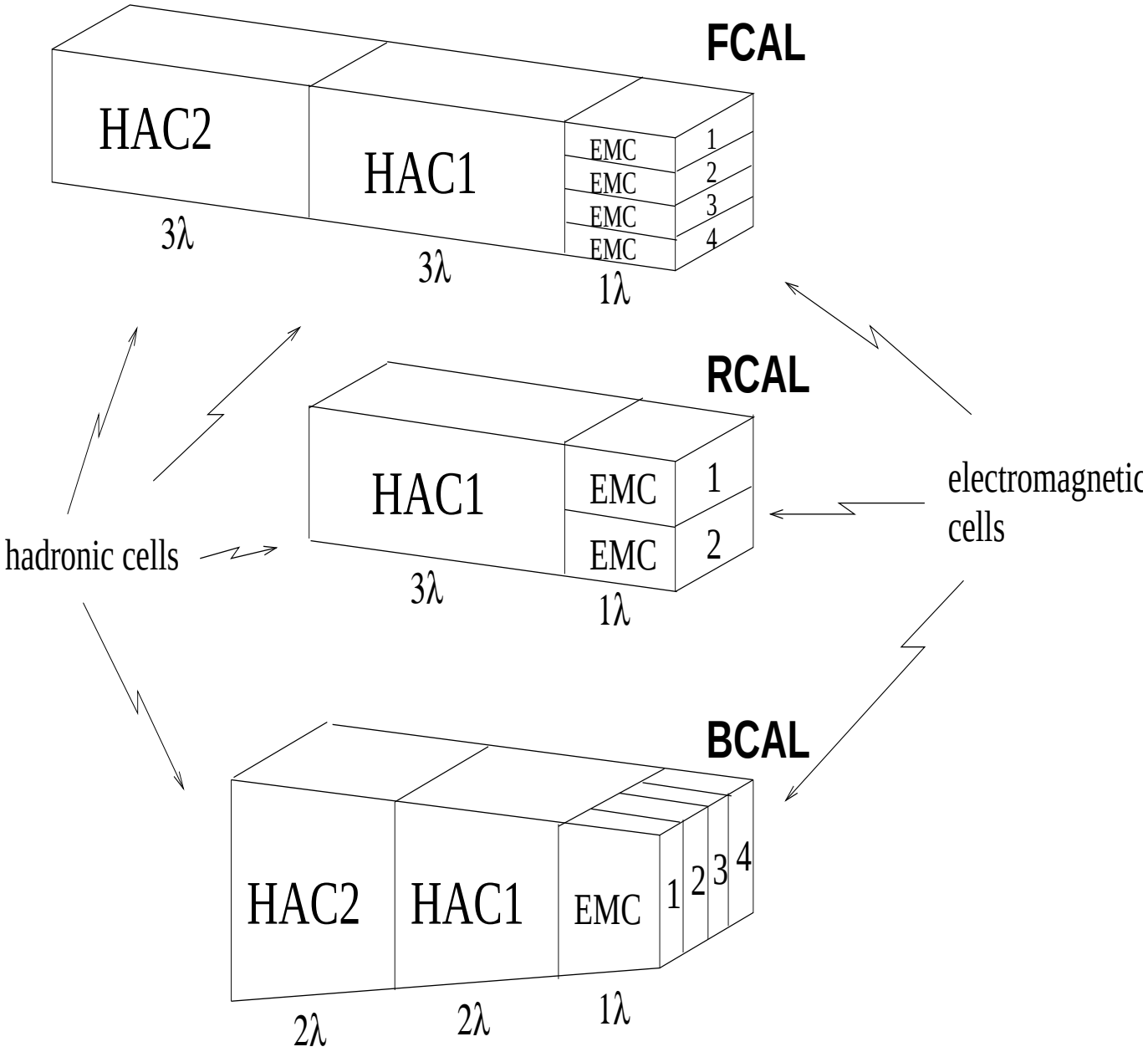
HAC1,2 : $2.1\lambda_I$
Depth : 1.08 m

RCAL ($4\lambda_I$)

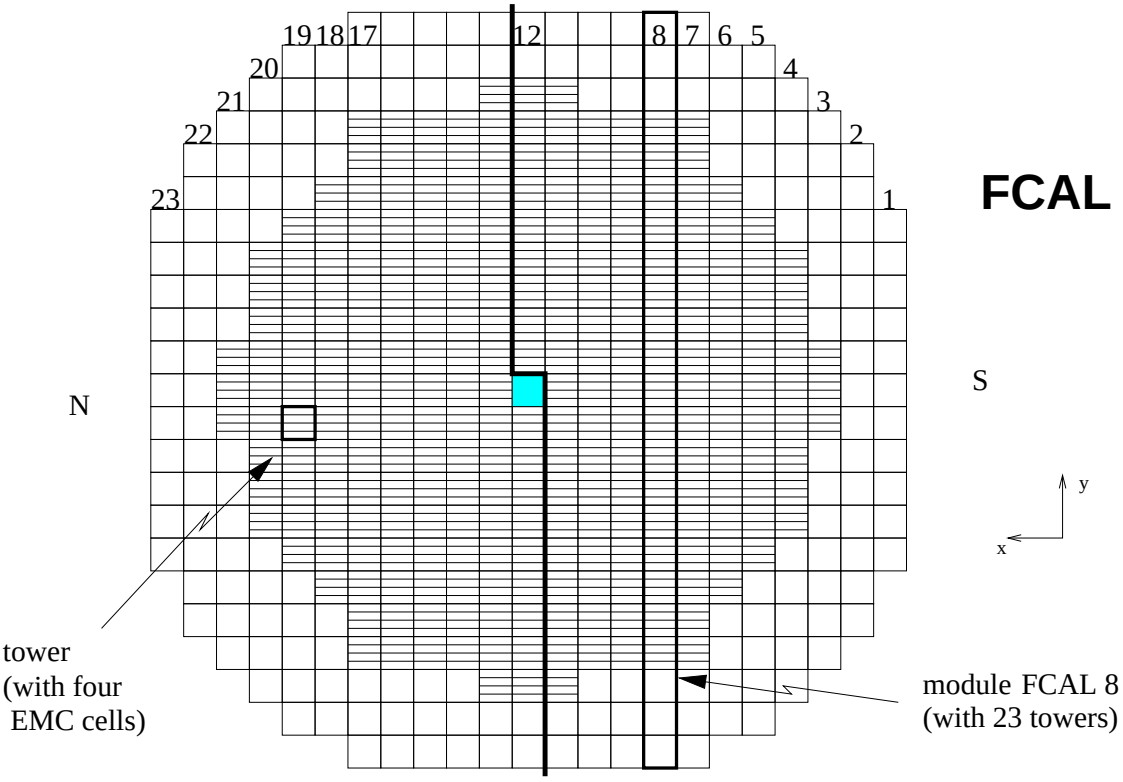
HAC1,2 : $3.1\lambda_I$
Depth : 0.9 m

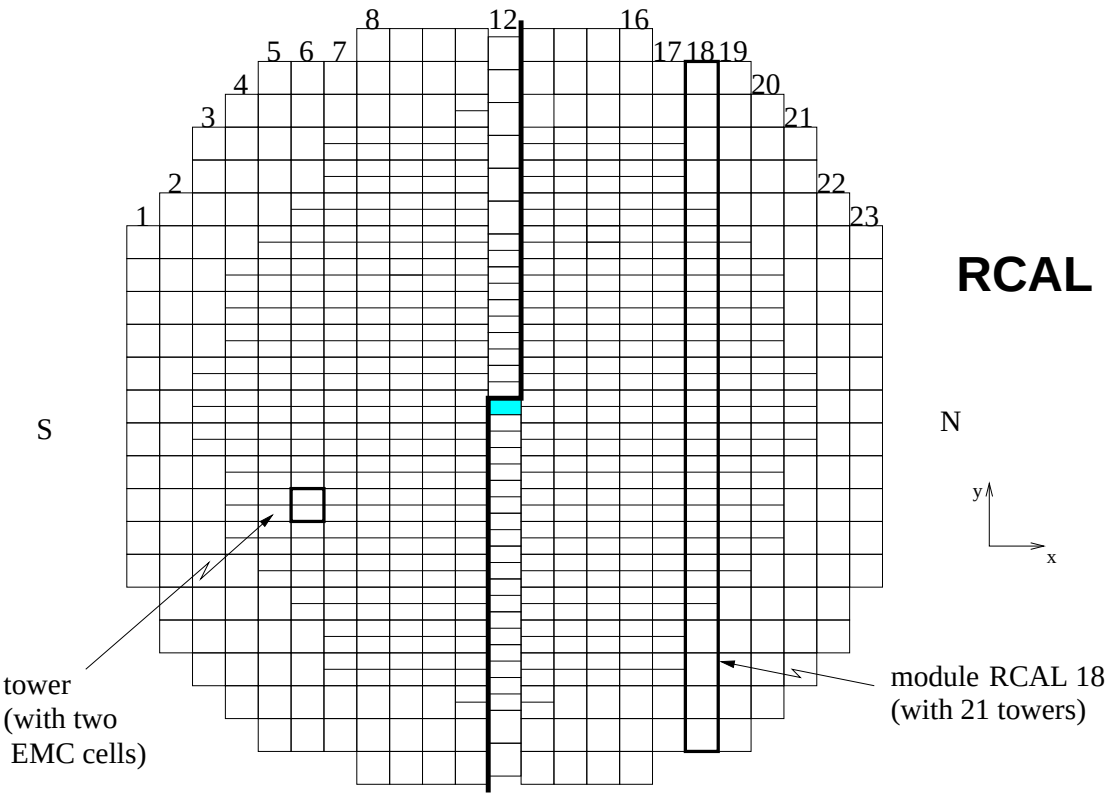
Calorimeter Characteristics

- EMCs are further subdivided longitudinally in 4 (2) sections in FCAL and BCAL (RCAL)
- HAC cells subdivided in 2 (1) sectors in FCAL (RCAL) and BCAL



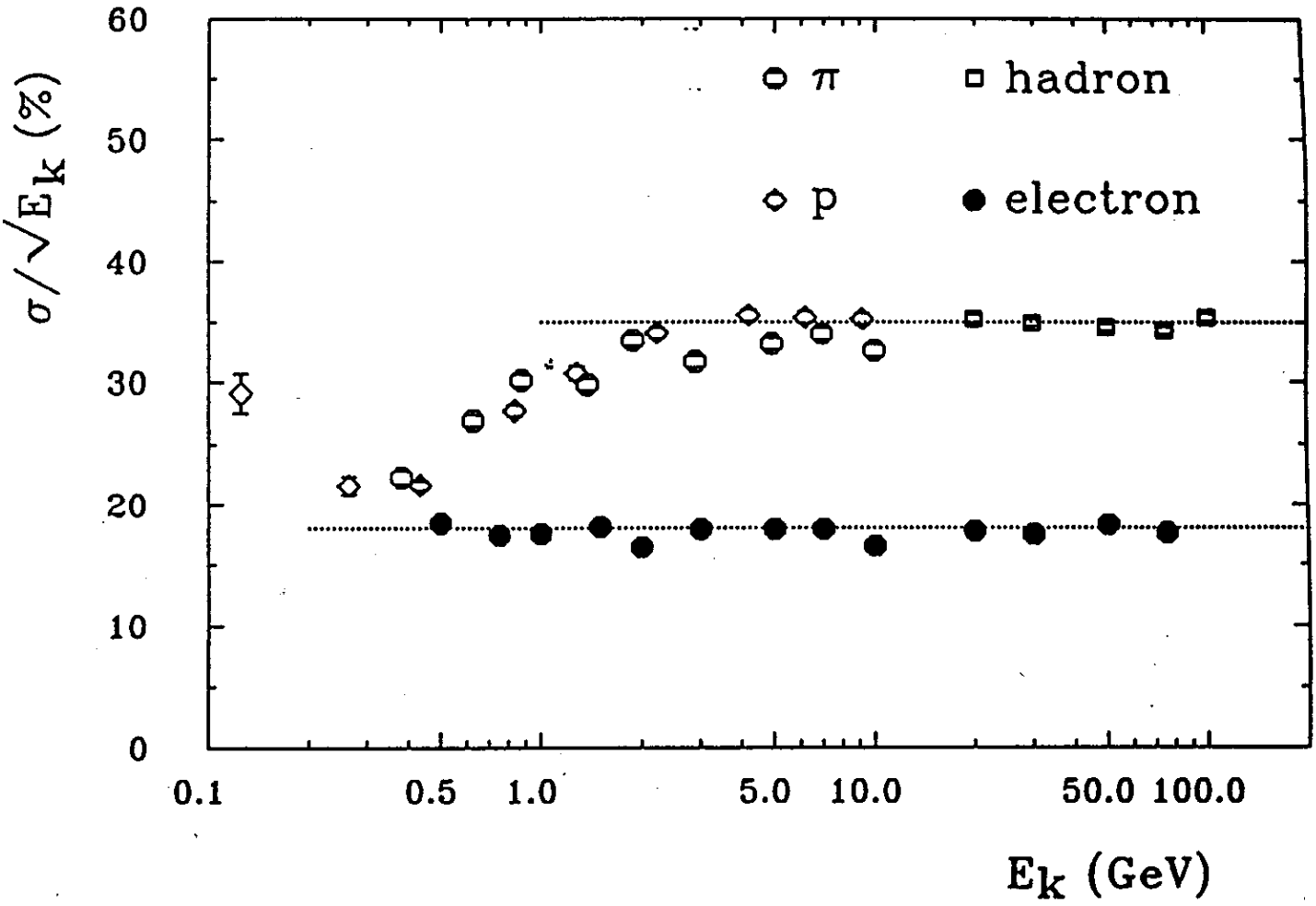
Calorimeter Characteristics





Calorimeter Characteristics

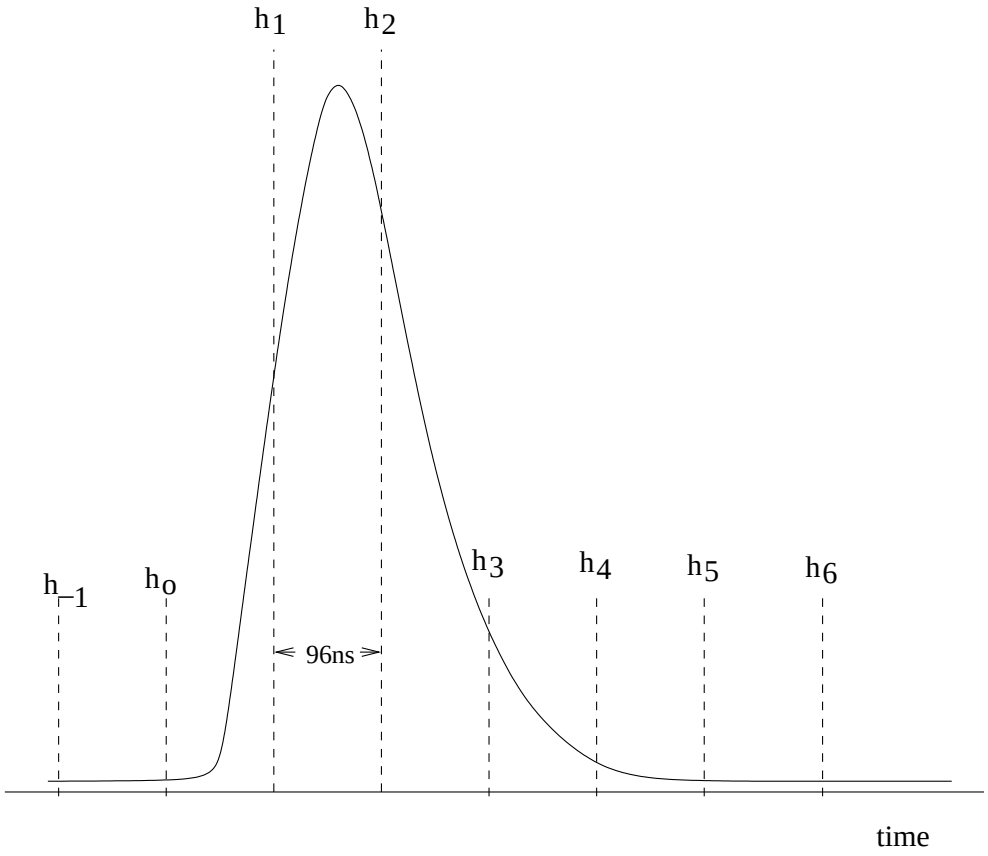
- High resolution
  - ⇒ electromagnetic energy $\frac{\sigma(E)}{E} = \frac{18\%}{\sqrt{E}}$
  - ⇒ hadronic energy $\frac{\sigma(E)}{E} = \frac{35\%}{\sqrt{E}}$
  - ⇒ Time resolution better than 1 ns
  - ⇒ Position resolution better than 1.3 cm vertically and 0.8 cm horizontally.



Calorimeter Characteristics

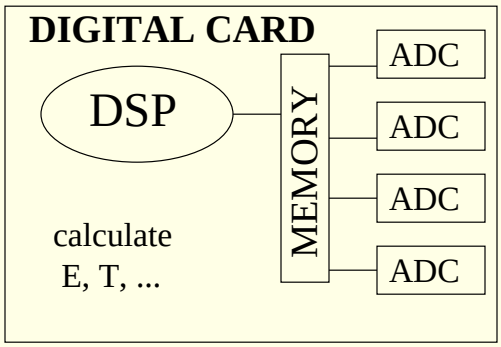
- Readout
  - Each cell viewed by 2 wave-length shifters (WLS) / Photo-multipliers (PMT) – total of 11836 channels
  - Front-end (analog) cards (FEC)
    - ⇒ Shape and amplify the PMT signal (high and low gain)
    - ⇒ Sample the signal and store it in a 10 MHz pipeline
    - ⇒ Buffer and multiplex the triggered events
    - ⇒ Integrate the Uranium noise, averaging over 20 ms
    - ⇒ Provide signal to Calorimeter First Level Trigger (CFLT)

Calorimeter Characteristics



Calorimeter Characteristics

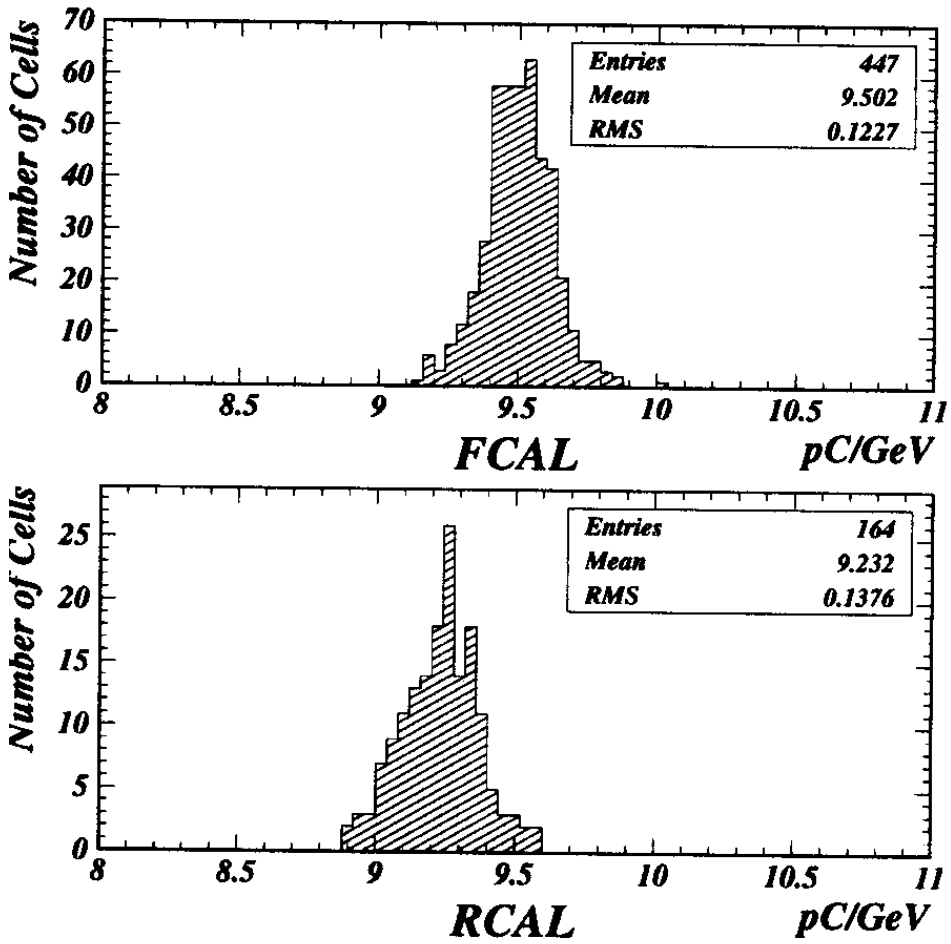
- Digital cards (DC)
  - ⇒ Memory
  - ⇒ Digital signal processor (DSP)
    - Corrects the samples
    - Calculates time and energy
    - Formats the output data for higher lever trigger processing
    - Performs monitoring functions
  - ⇒ ADCs to Digitize signals from FECs



- Very low dead time - 1.5% at 1 KHz FLT rate
- Noise level dominated by the uranium activity (UNO) of ≈15 (≈25) MeV in the EMC (HAC) sectors
- Dynamic range/cell (high gain)(low gain) of
  - (0-24 Gev)(0-530 GeV) in FCAL,
  - (0-18 Gev)(0-380 GeV) in BCAL and
  - (0-18 Gev)(0-90 GeV) in RCAL

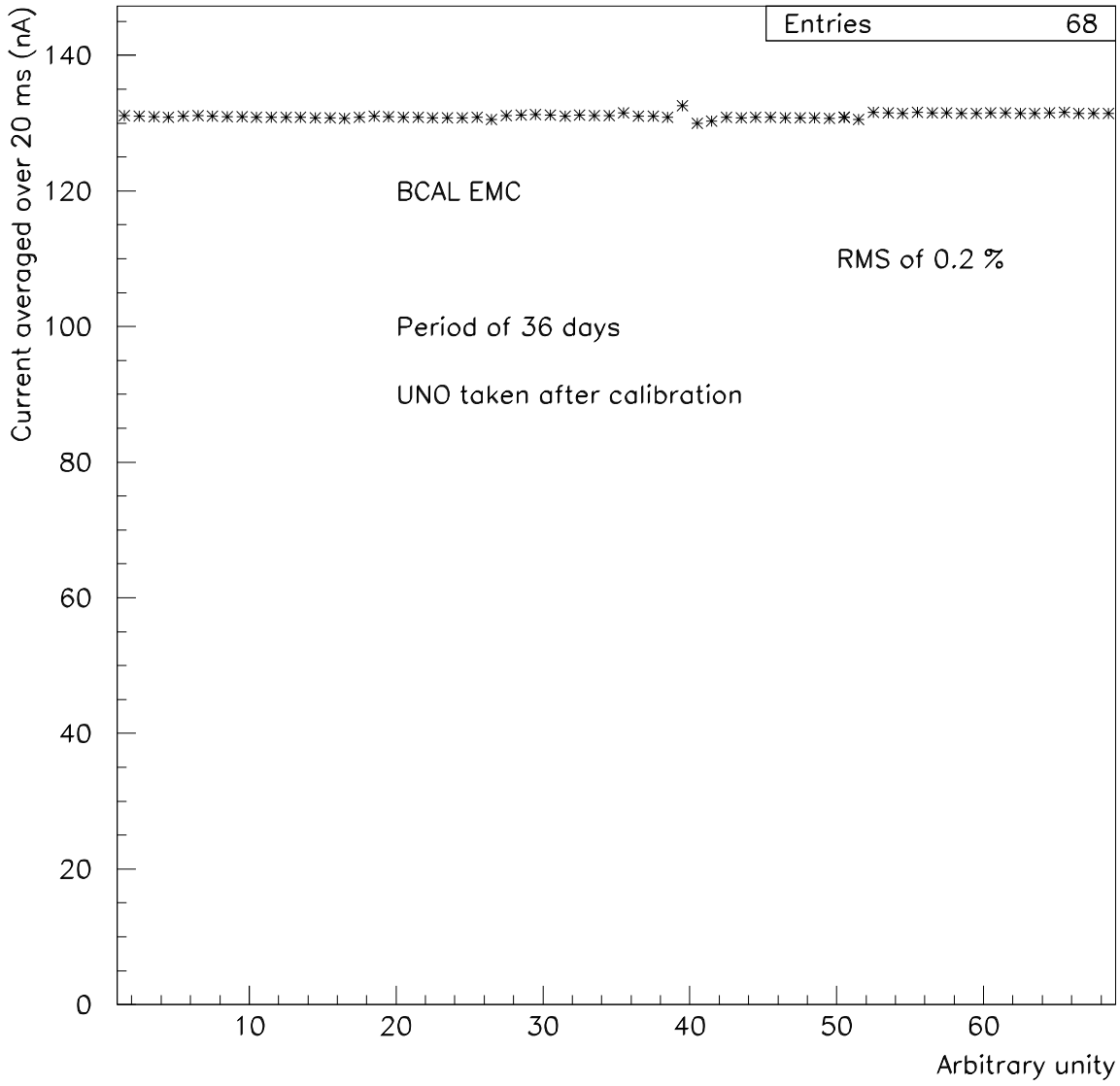
Calibration Method

- Idea
  - Uniform structure throughout the entire calorimeter
  - Natural uranium activity provides the absolute energy calibration.
    Uranium noise at 2-10 MHz/cell
  - Cell to cell calibration at 1% (2%) level for EMCs (HACs) at test beam.



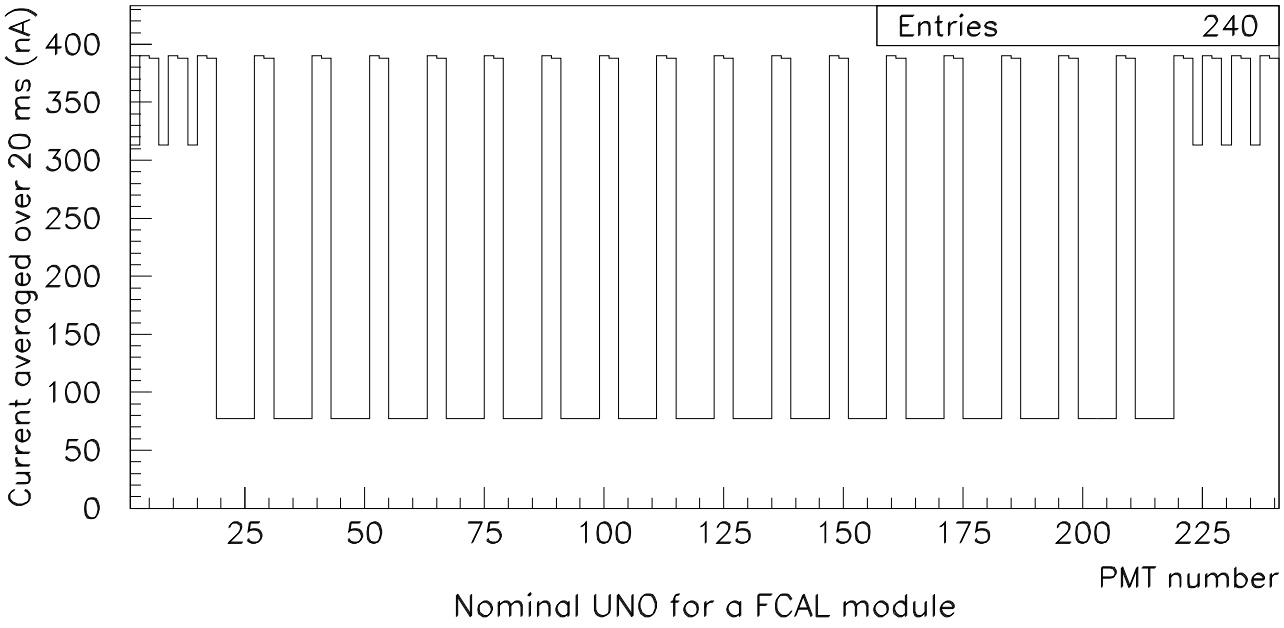
Calibration Method

- Calibration factors transported from test beam to ZEUS
- High Voltages to the PMTs are adjusted to restore the nominal UNO current
- UNO offset values are measured

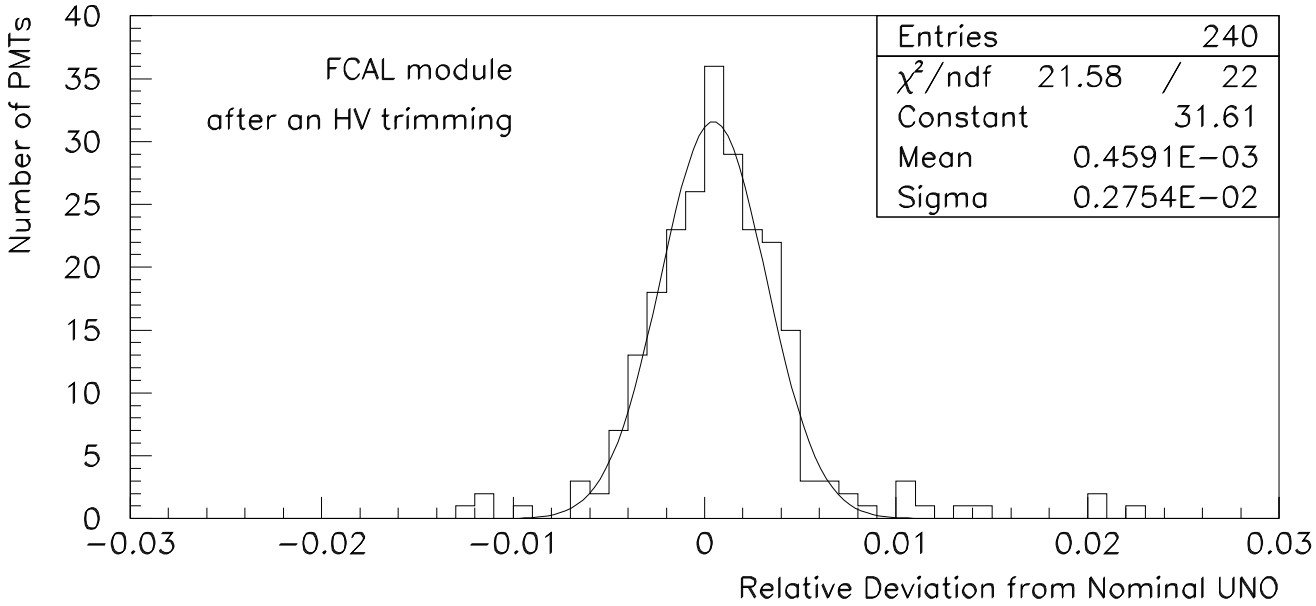


Calibration Method

- Deviation from nominal UNO better than 1%

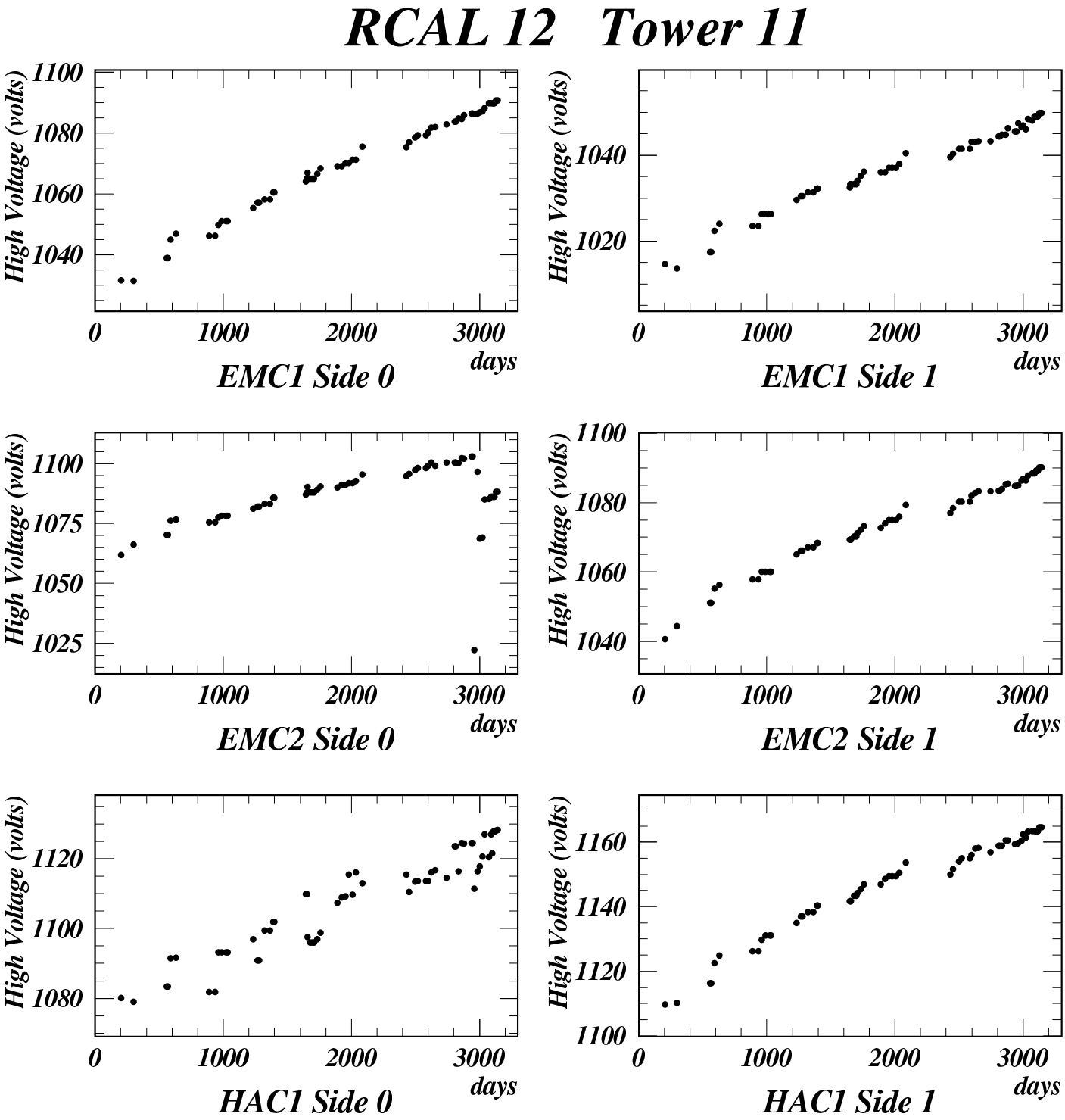


Nominal UNO for a FCAL module



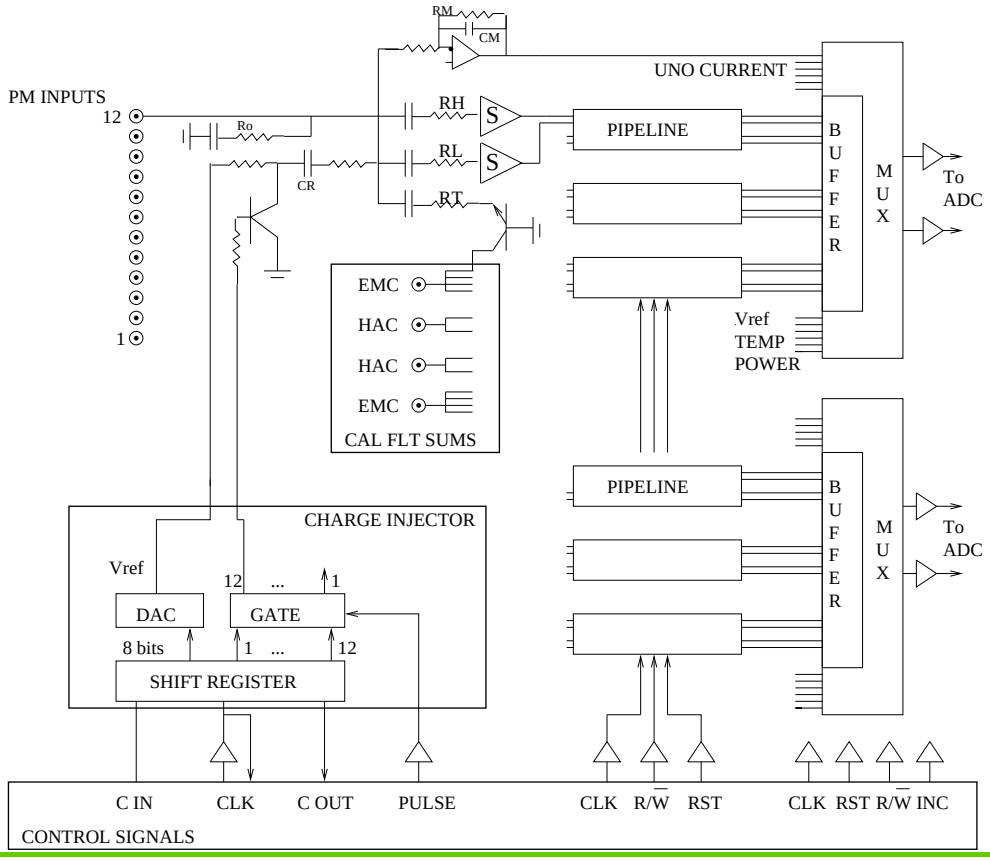
Calibration Method

- PMT gain changes from 1992 to 2001



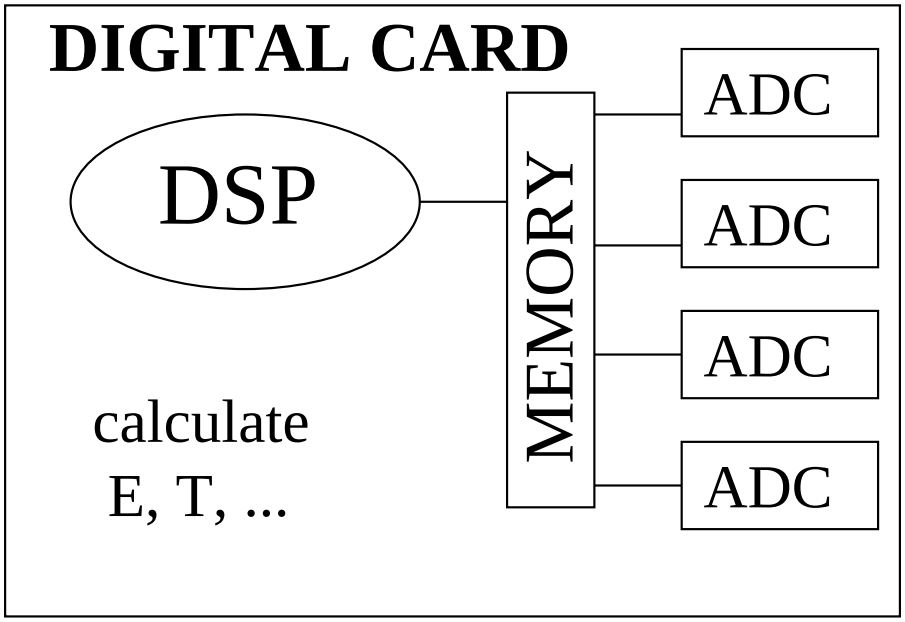
Calibration Method

- Electronic Calibration
  - Precise reference voltages generated on board of each FEC
    - ⇒ Used to measure pedestal and gain of the pipeline and buffer chips
    - ⇒ Injected in the buffer-multiplexer and used to calculate the ADC-to-Volt constants
  - Stable and known amount of charge injection (Qinj) is used to calibrate the gain of the shapers



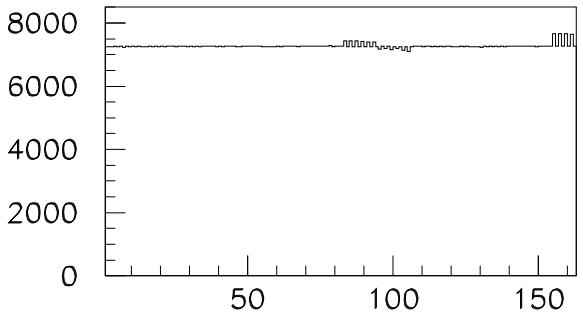
Calibration Method

- The calibration constants are stored in the DC card memory and used by the DSP to correct the sample and calculate the energy and time.
- Calibration stable to much better than 1% over a week

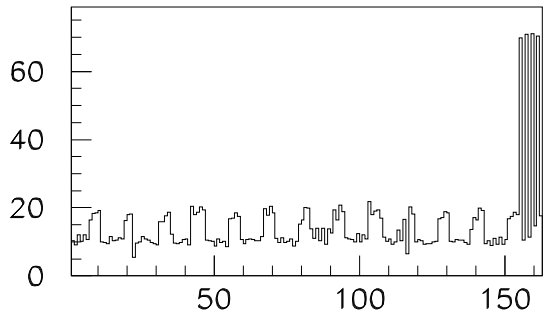


Monitoring

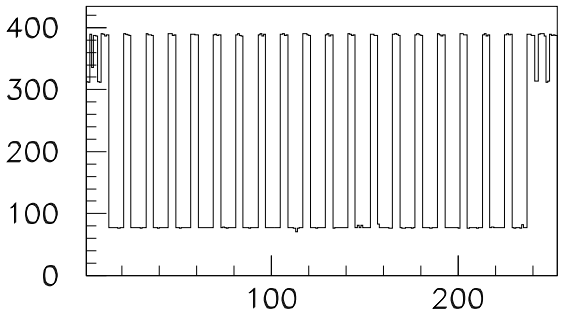
- Check the calibration stability
- Mark bad channels
  - Measure pedestal of the entire readout
  - Measure UNO
  - Inject stable charge in the shapers



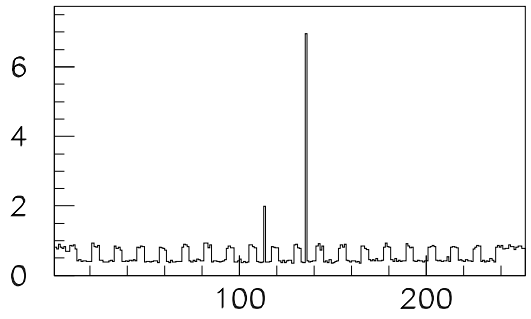
Qinj x PMT number



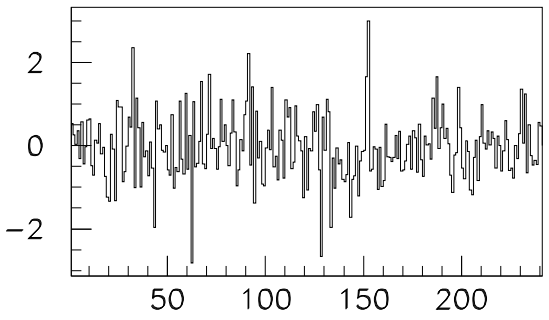
Qinj RMS x PMT number



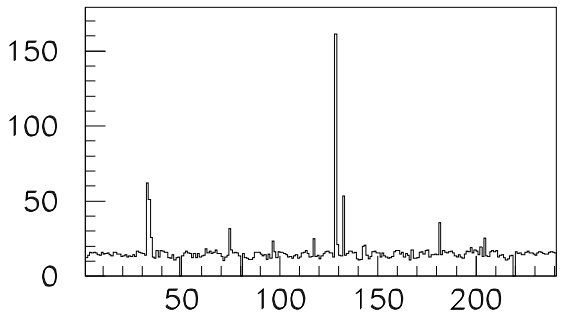
UNO x PMT number



UNO RMS x PMT number



Pedestal x PMT number



Pedestal RMS x PMT number

Monitoring

- In addition
  - Pulse of laser and LED light injected in the WLS
    - $\Rightarrow$ can be used to check the PMT gain stability
    - $\Rightarrow$ can check the PMT linearity over a wide dynamic range
- HV trimming done twice a week
- Full electronic calibration done once a week
- Bad channel monitoring and energy scale update are done on daily basis
- Present status
  - Only 2.4 % of bad channels
  - Recent radiation source scan shows very low radiation damage

Summary

- The compensation mechanism allows the ZEUS Uranium Calorimeter to achieve good hadronic resolution
- The uranium activity was used to bring the absolute energy scale from test beam to ZEUS
- The losses in the PMT gain are compensated by adjusting the high voltage using the UNO
- Complete full electronic calibration good to 1%
- Daily calibration
- As a result, calibration is stable to 1-2%
- But.... Absolute calibration from test beam to ZEUS good only to 3-4%.
  Correct using physics constraints
  (see M. Wing's talk).