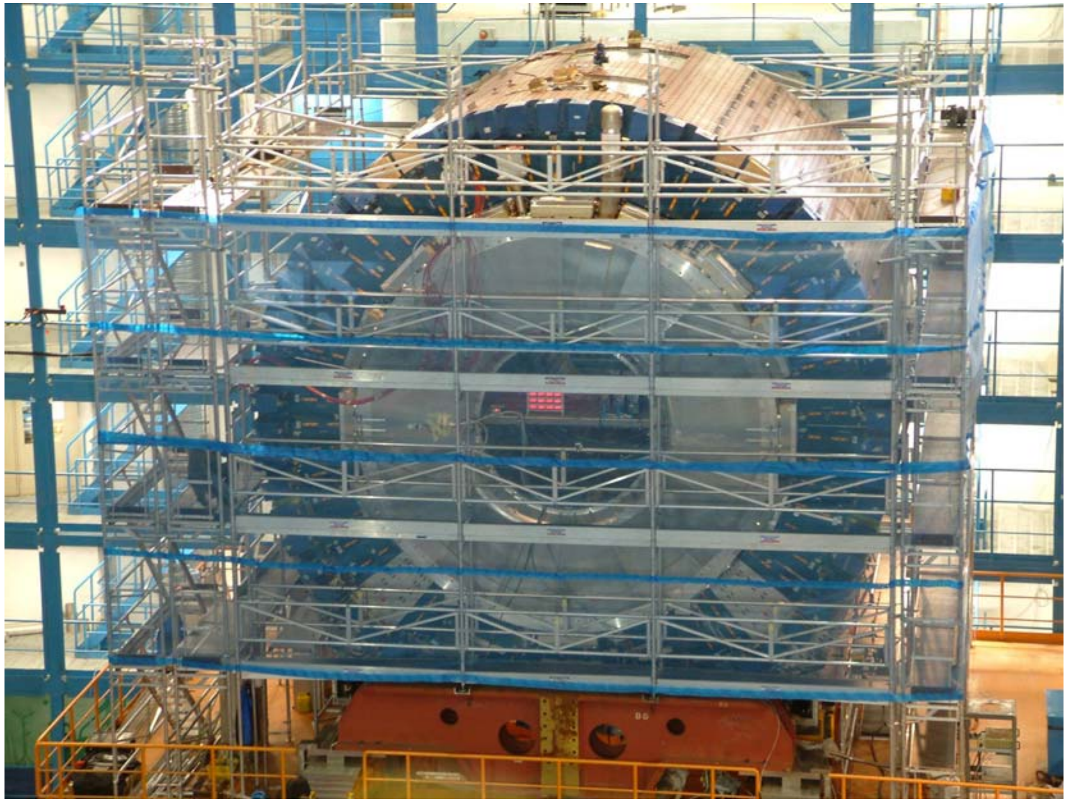
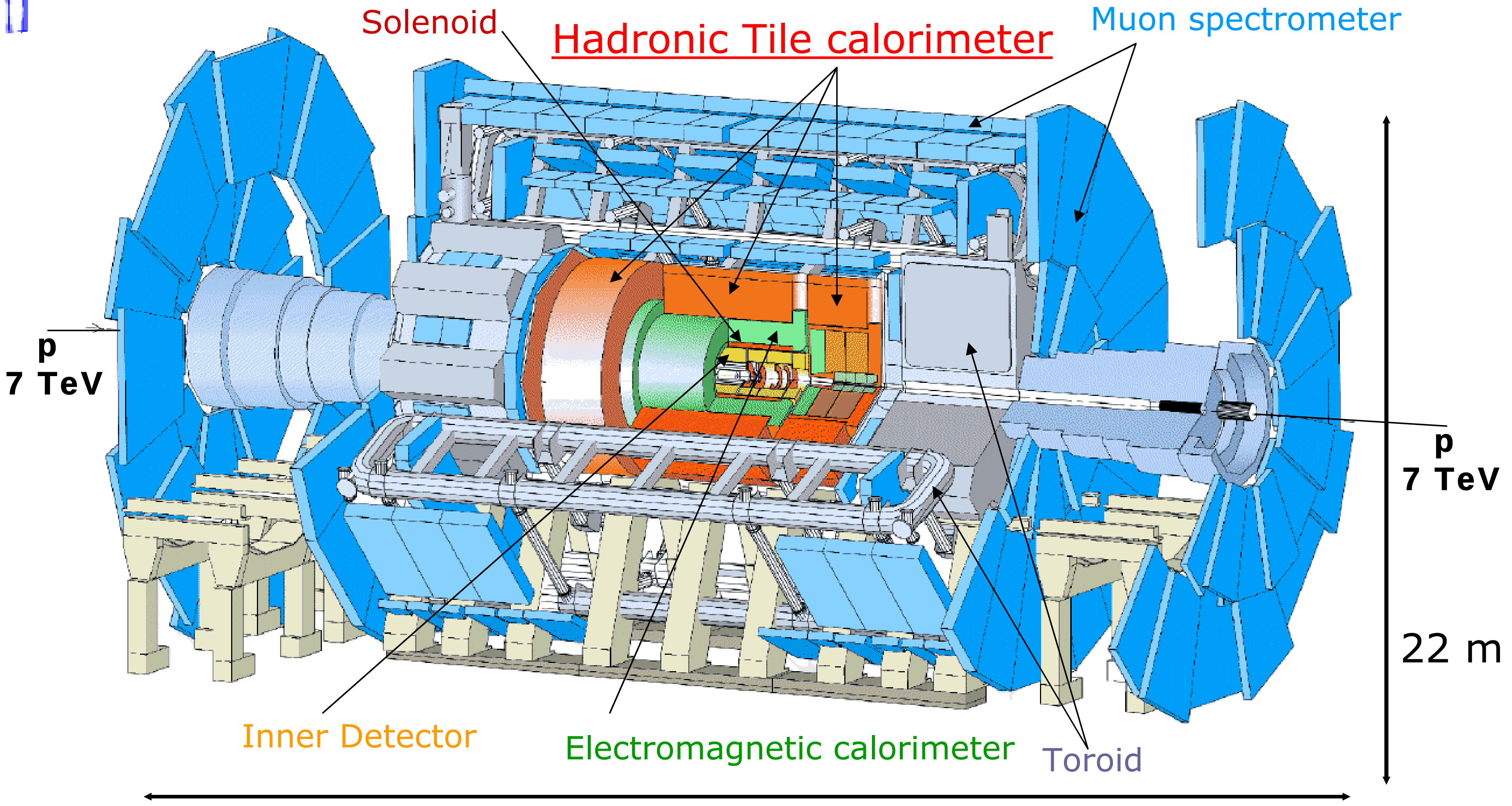
Calibration and monitoring of the ATLAS Tile Calorimeter

presented by João Carvalho (LIP-Coimbra)
on behalf of ATLAS TileCal Collaboration



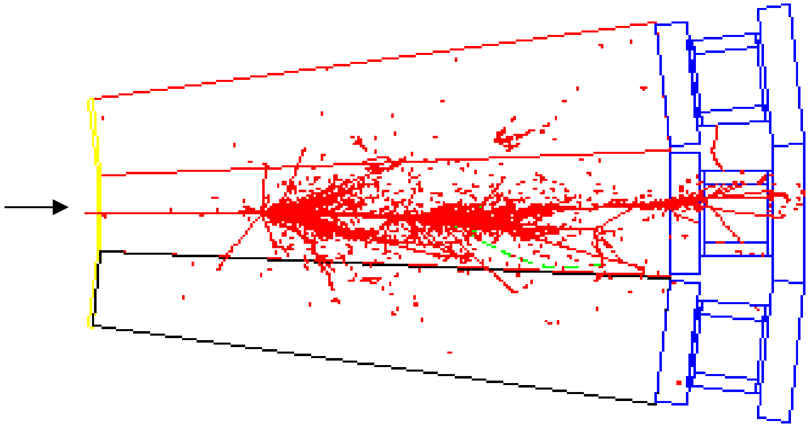
ATLAS detector

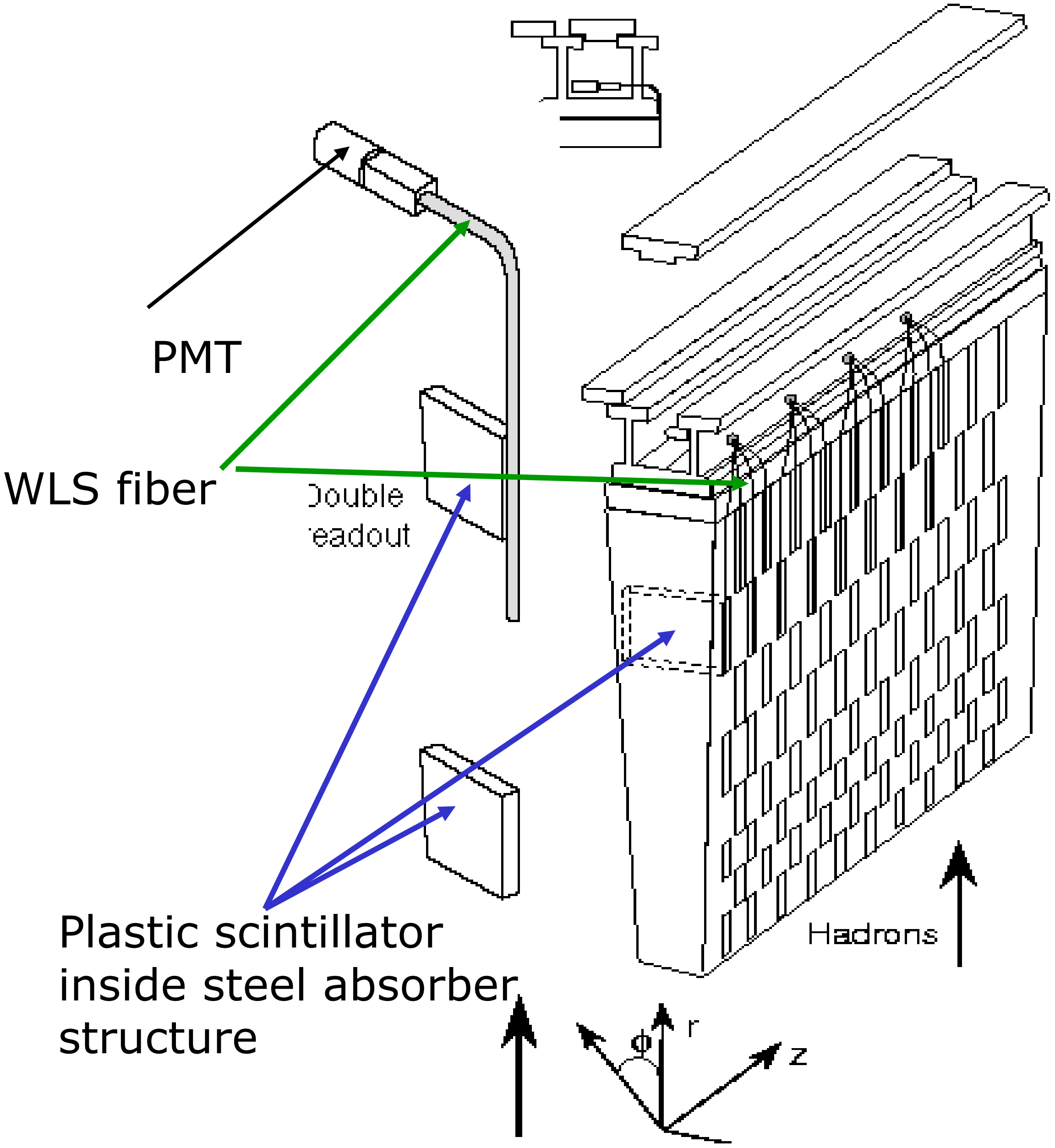


Total weight ~ 7000 t

Principle of TileCal:

Measure light produced by charged particles in plastic scintillator





PMT

WLS fiber

Plastic scintillator inside steel absorber structure

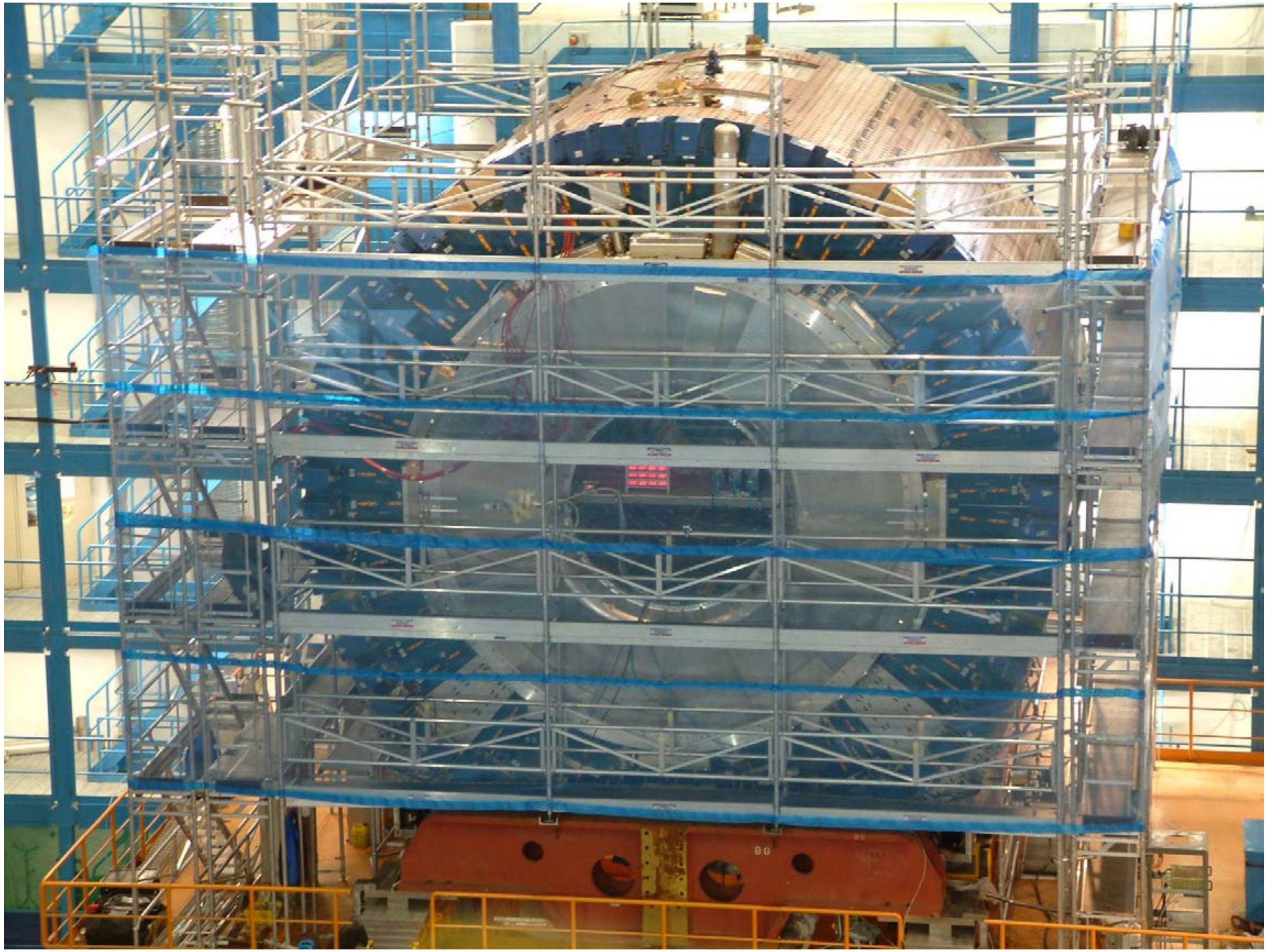
Testbeam measurements

- 8% of the modules calibrated at testbeam with particles of known energies (from 1 to 350 GeV)
- Measurement of the response to pions, electrons and muons
- Different energy reconstruction algorithms tested

Calibration triggers: CIS, Laser, Pedestal runs. They will be used for monitoring and calibration in ATLAS

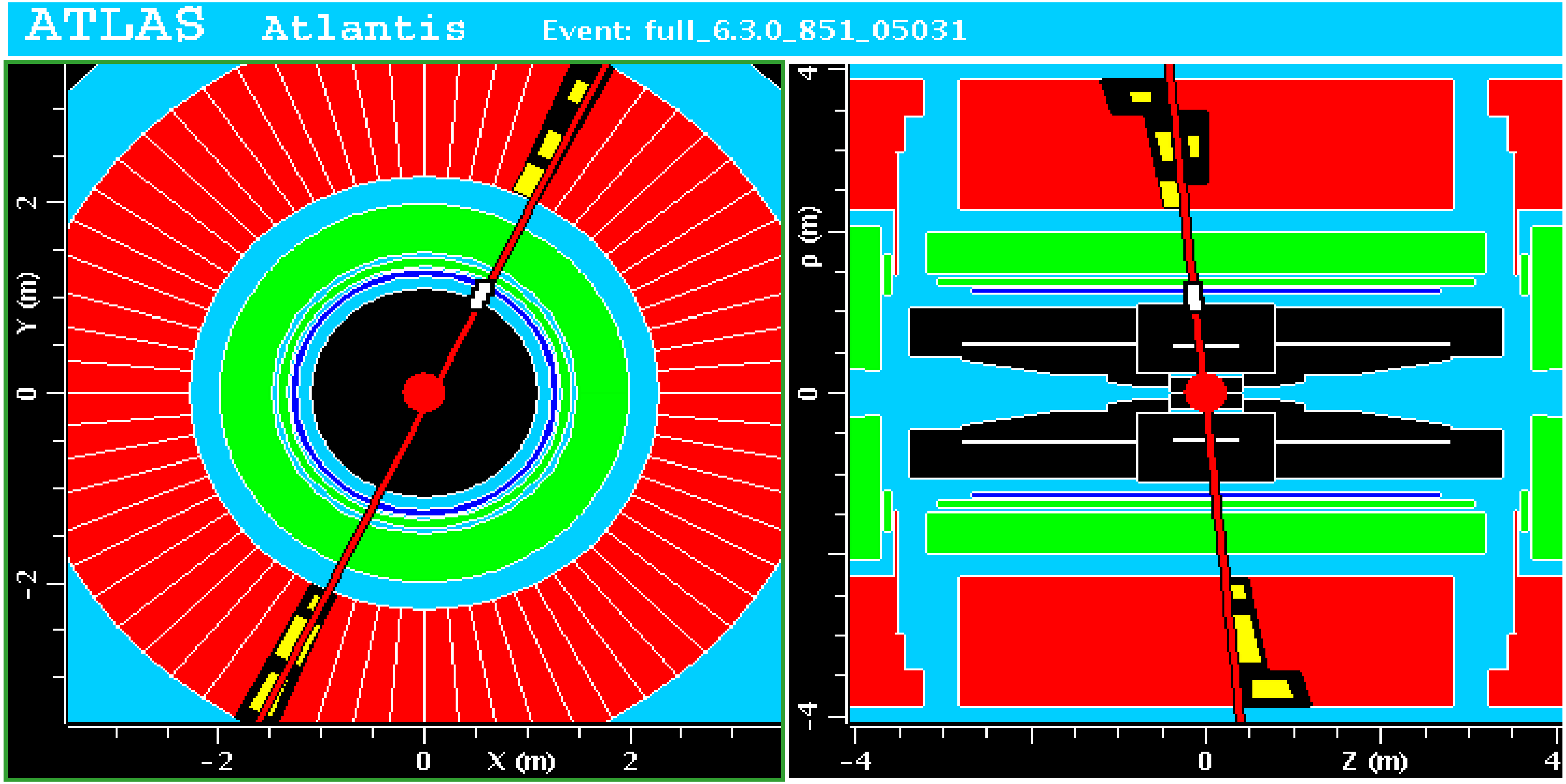
Tilecal assembly in the pit

It is already installed and in commissioning phase in the pit

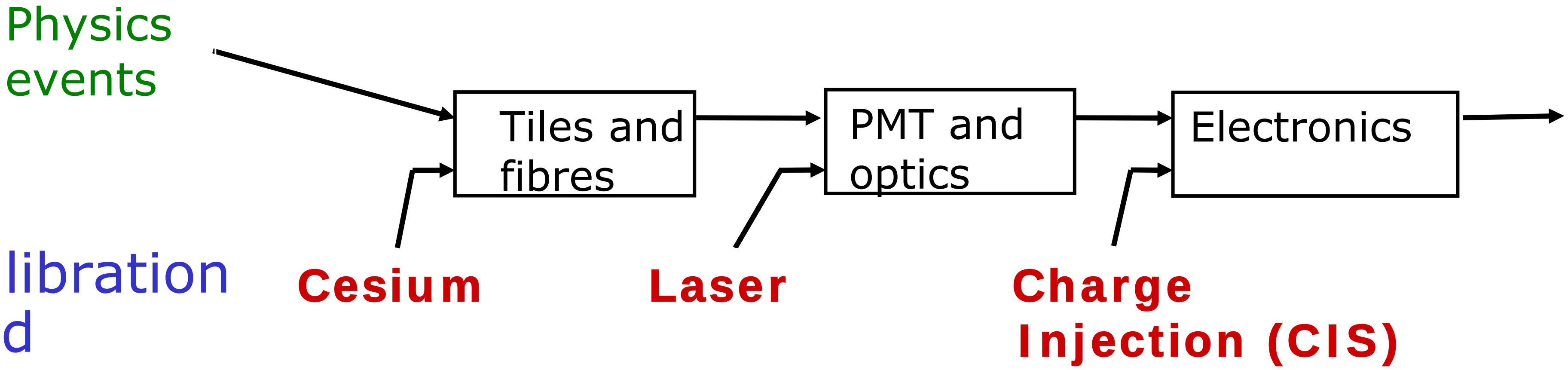


Cosmics triggered by TileCal

(commissioning)



Calibration and monitoring



Physics events

Tiles and fibres

PMT and optics

Electronics

Cesium

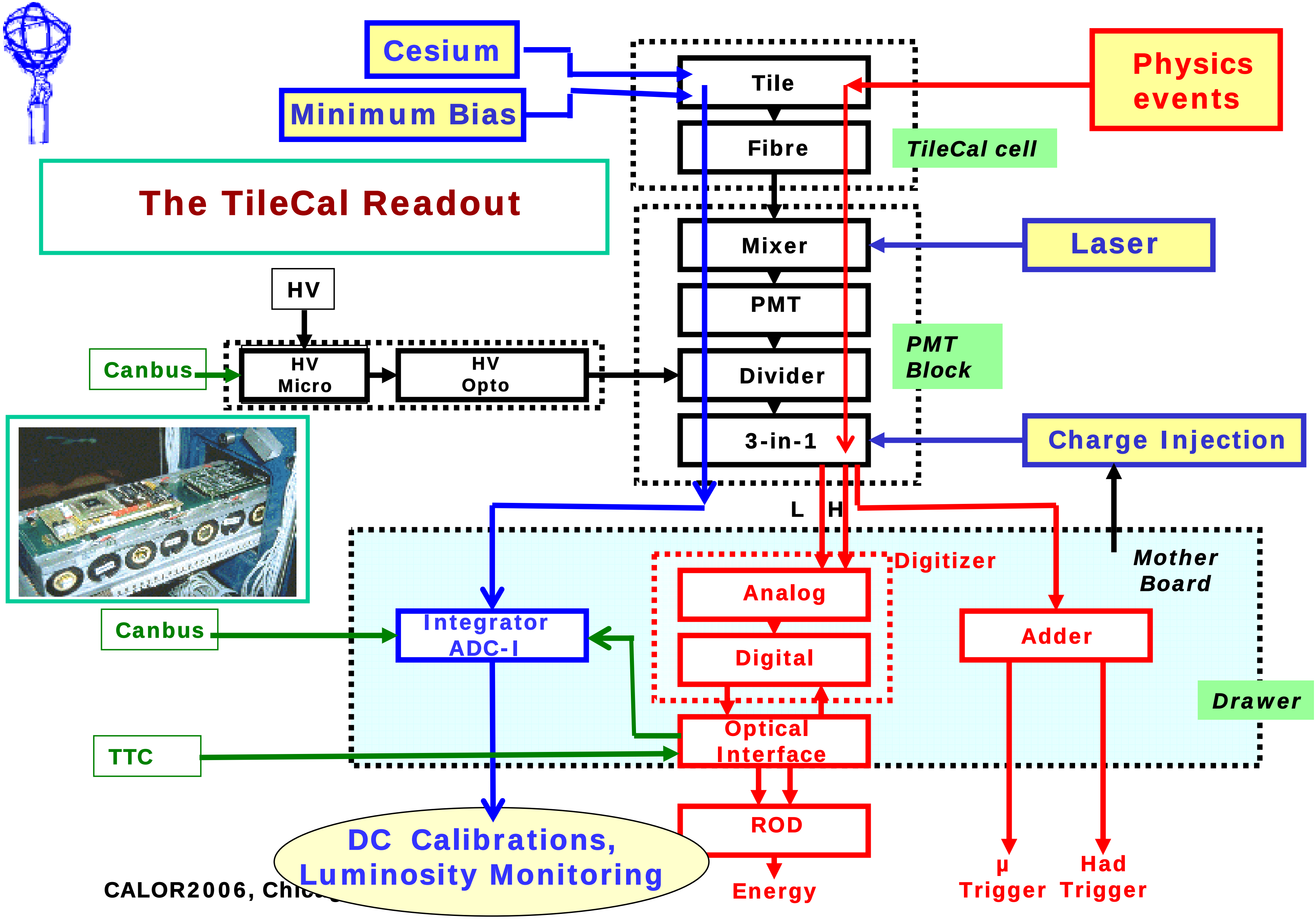
Laser

Charge Injection (CIS)

Calibration and monitoring systems

Diferent parts of TileCal readout are monitored and calibrated by the various systems

The TileCal Readout



Charge Injection System (CIS) overview

- Inject charge, from a high precision voltage source, into calibration capacitors (then discharge then into the electronics)
- To calibrate and monitor pulse readout electronics at O(1%) level
- Demonstrate linearity over the working range for physics signals
  - Watch for time evolution of linearity
- Determine properties of the readout system
  - Low gain: 1023 ADC counts / 800 pC = 1.3 counts / pC
    - 800 pC full scale (~700 GeV) / channel
  - High gain: 1023 counts / 800 pC * 64 = 82 counts / pC
    - Muon in A-cell PMT $\Rightarrow$ 0.2 pC (17 counts)

CIS Usage in ATLAS

Periodic CIS runs over full dynamic range during beam-off periods

- Between LHC fills
- During maintenance periods
- Frequency to be determined by experience
  - More frequent initially
  - Less frequent once stability is demonstrated

Interleaved with data (mono-CIS events)

- Inject fixed amplitude signal during missing bunch interval in LHC beam structure

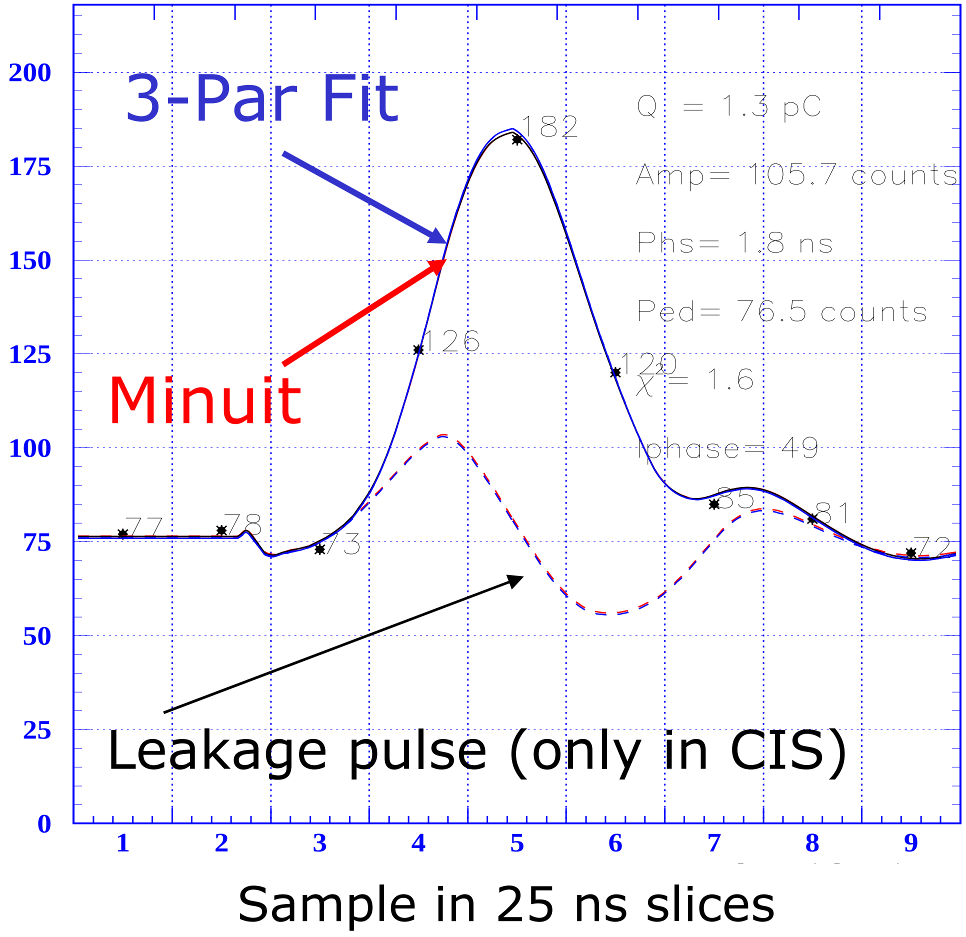
Signal Reconstruction of CIS Data: Three-Parameter Fit

- Least squares fit for 3 parameters:
  - TFit*N* (*i*) Time (ns)
  - PedFit*N* (*i*) Pedestal
  - EFit*N* (*i*) Amplitude

(Tile module *N*, PMT *i*)

- CIS constants to convert ADC counts to energy in units of pC (via precision 100 pF capacitor)

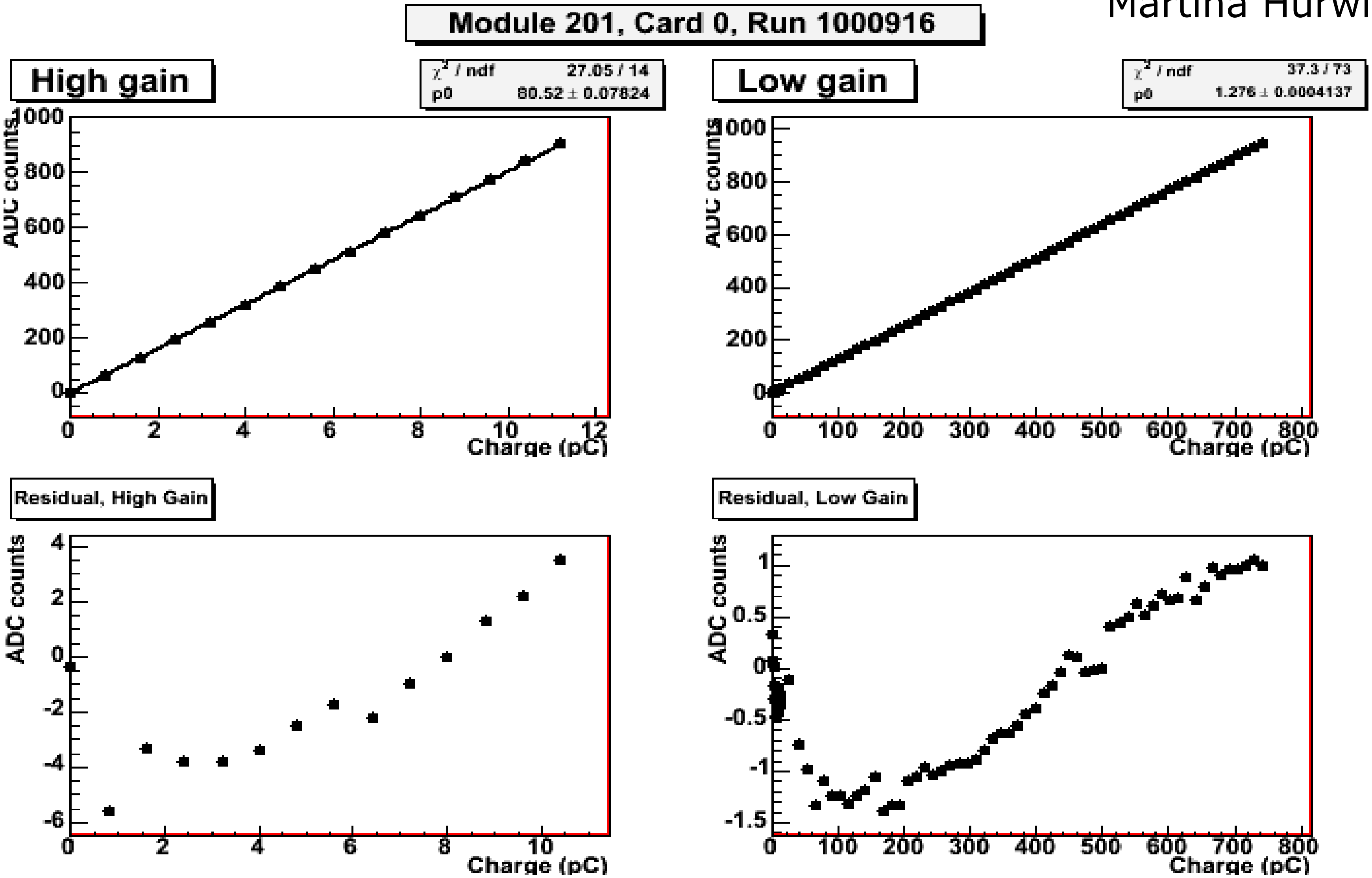
Example of 3-Par Fit to CIS data



Example of ADC/pC fit (CIS run CTB ‘04)

One channel

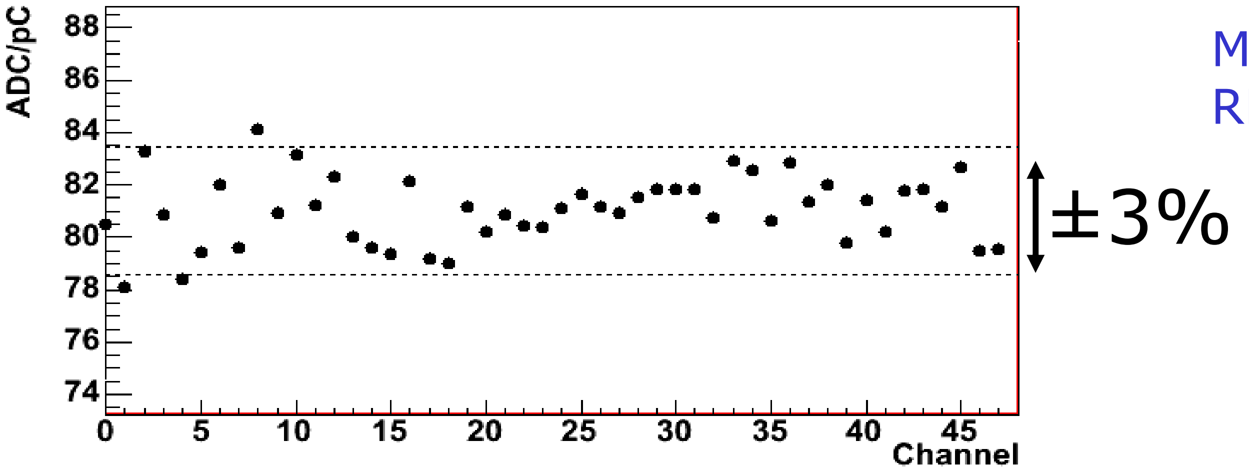
Martina Hurwitz



Channel-to-channel variation (CTB ‘04)

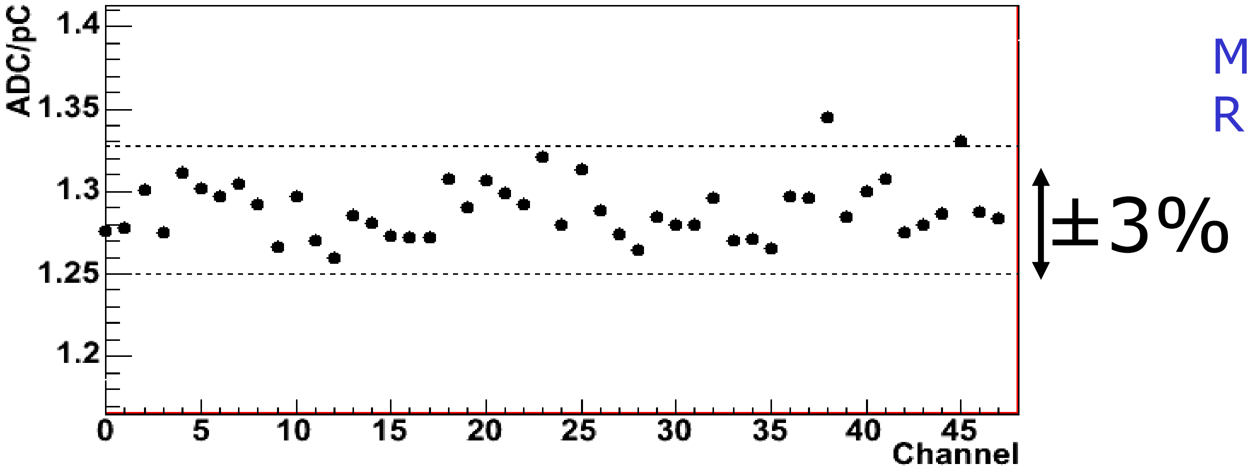
Module 201, Run 1000916

High Gain



Mean = 81.02 counts/pC
RMS = 1.31 counts/pC (1.6%)

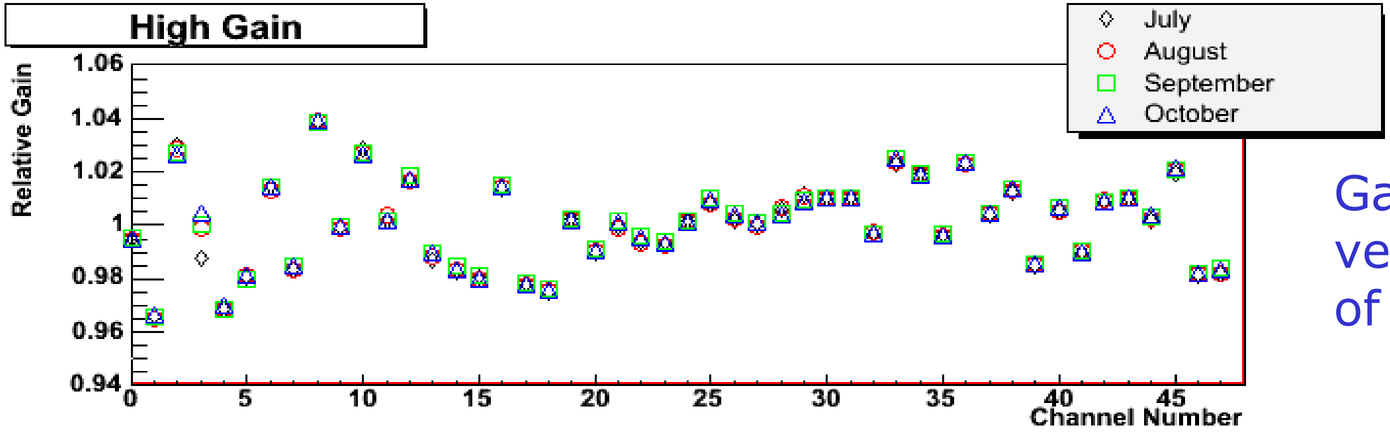
Low Gain



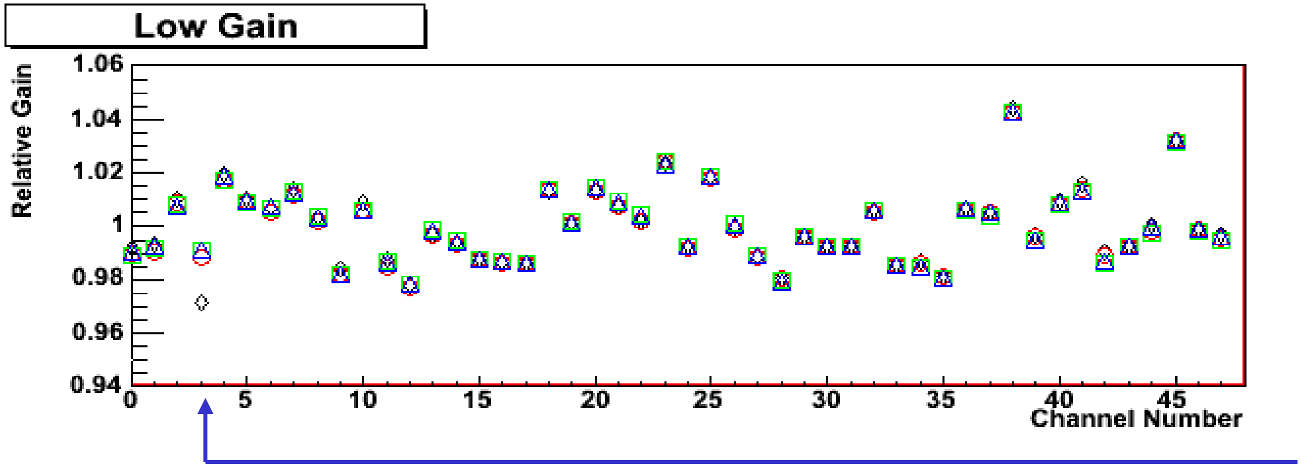
Mean = 1.29 counts/pC
RMS = 0.018 counts/pC (1.4%)

Evolution of calibration constants (CTB ’04)

Middle Module (201, C-side)



Gains in most channels very stable over course of four months



2% decrease in gain in channel 3 between September and October. Seems to be real effect

Laser calibration

Laser data used for:

- monitoring the stability (and correction) of gain O(0.5%);
- checking the linearity of PMTs;
- studies on saturation recovery;
- studies on the calorimeter timing (synchronization)

Laser system

-One clear fiber from the laser goes to every module and it's split to all PMTs

-Contrary to Cesium system, Laser system may monitor short-term stability of the PMT

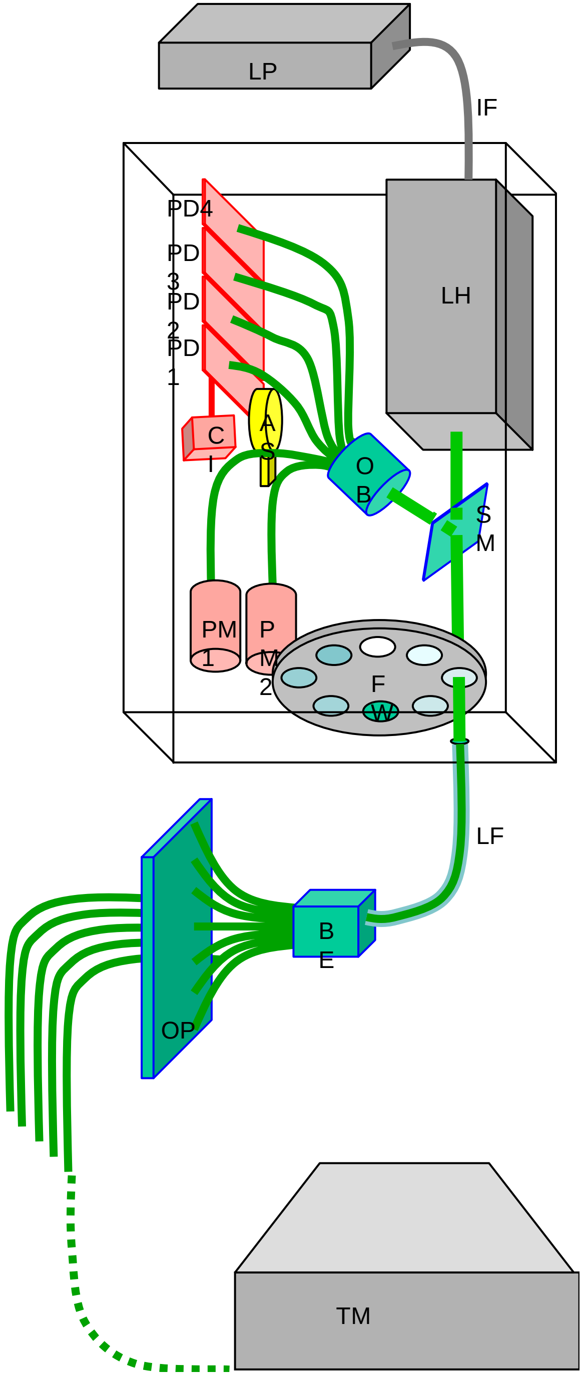
-Special Laser Runs will be taken in ATLAS:

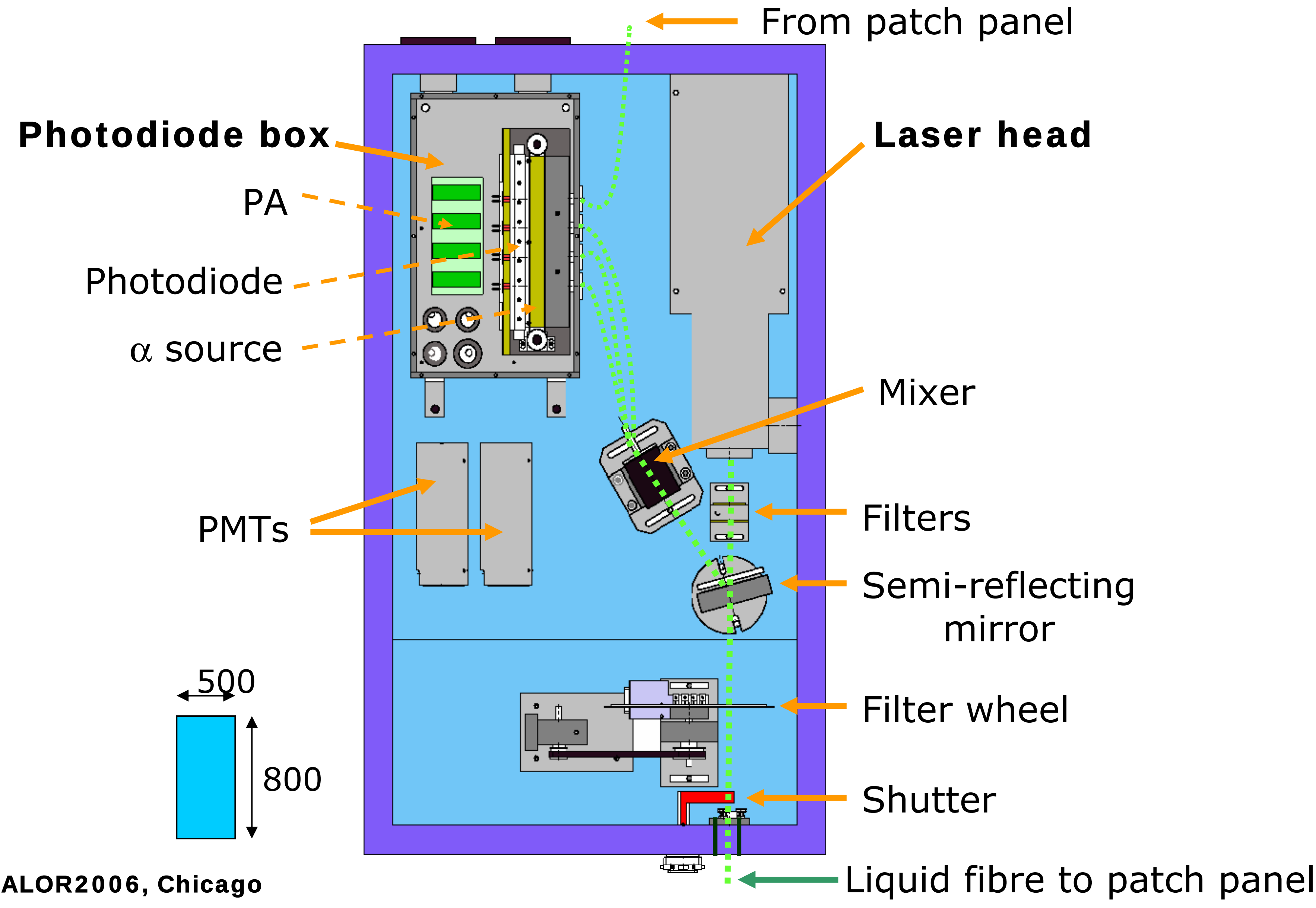
  - Linearity Runs (Multi-pulse) over the whole dynamics (16 bits ~ 60000)
  - Saturation studies (Multi-pulse): well above the limit of 800 pC (~1.4 TeV/cell)

- Measurement of the number of photo-electrons (Mono-pulse)

  - Very high amplitudes similar to high energy jets below saturation (Mono-pulse)
  - Very low amplitudes similar to muons (Mono-pulse)

- Timing measurements





From patch panel

Photodiode box

PA

Photodiode

α source

Laser head

Mixer

PMTs

Filters

Semi-reflecting mirror

Filter wheel

Shutter

Liquid fibre to patch panel

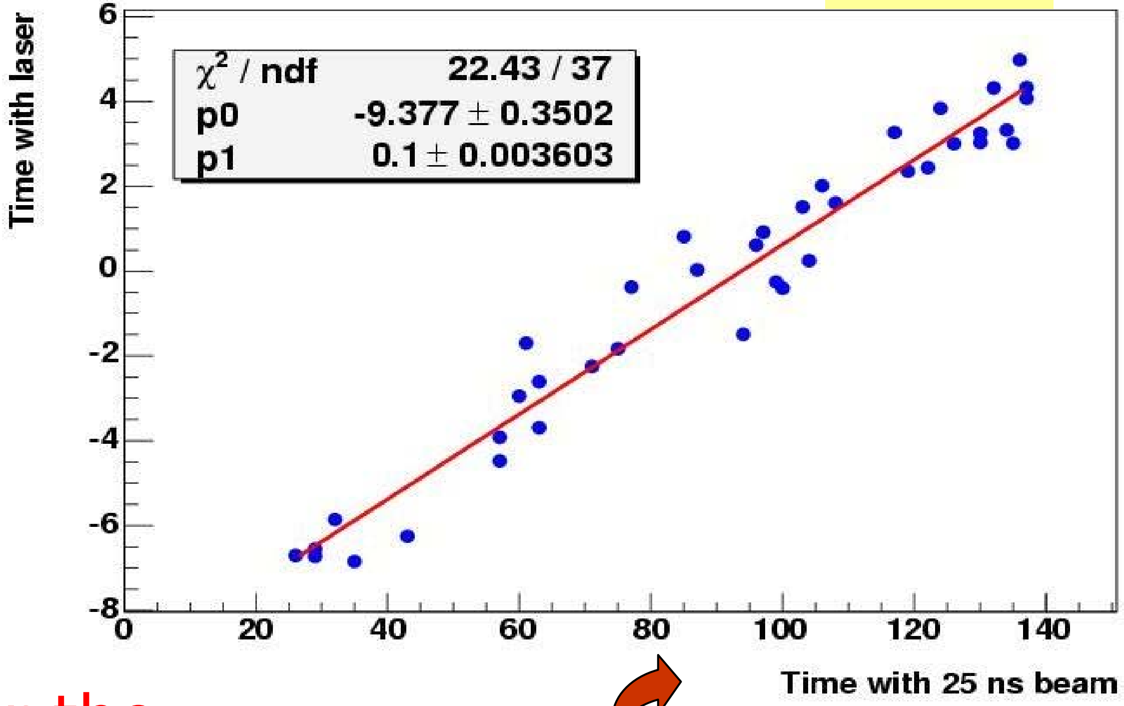
500

800

Timing results

What we want: signal of projective particles must be synchronous with clock

Taking into account the differences in the propagation of signals, timings done with projective particles and with laser can be easily correlated!

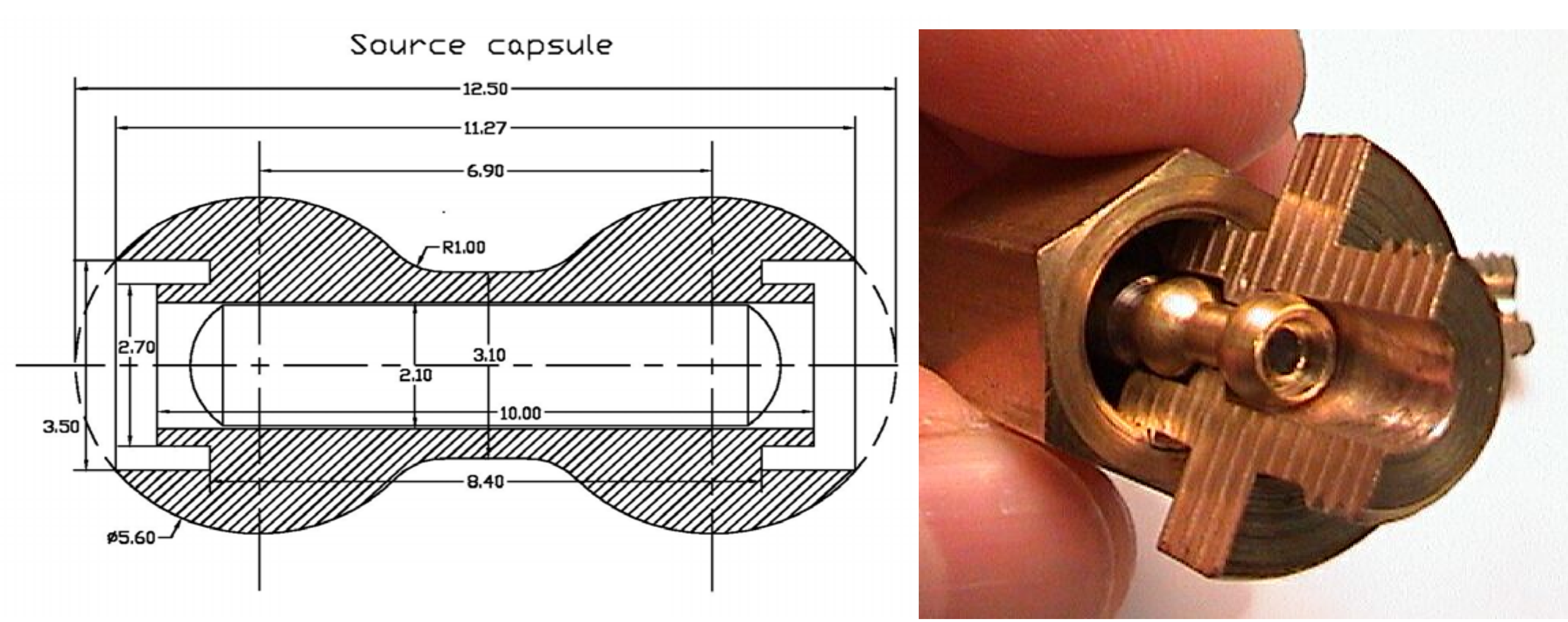


Barrel

1 unit is 104 psec

Laser can be used for the calorimeter timing

Cesium calibration system

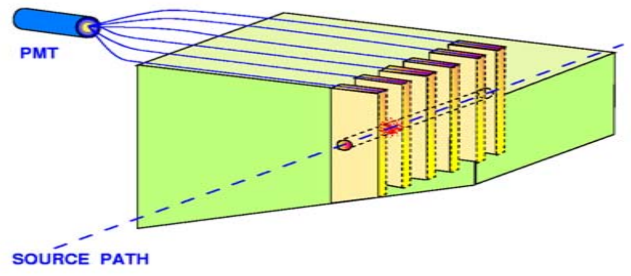


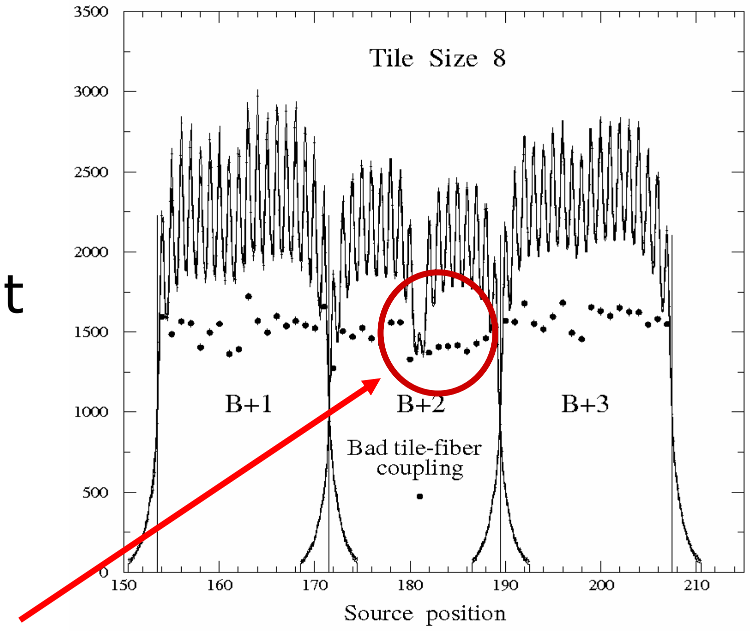
Cs source capsule design and the sample of an empty capsule.

Cs system produces a TileCal “X-ray”

Cesium calibration system overview

- Cesium calibration system is based on a movable 9 mCi ^{137}Cs γ-source
- Source is transported by a hydraulic system to excite every scintillator tile.
- Current in PMTs connected to the cell is measured by an integrator circuit
- The goal of the Cesium calibration system is:
  - To check the quality of the optical response and its uniformity
  - To equalize the response of all read-out cells
  - To monitor each cell over time and to maintain the overall energy calibration at a precision of 0.5%



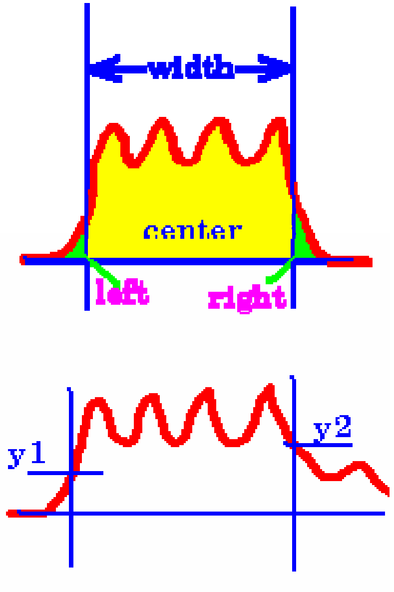


Detection of bad tile-fibre coupling

Calculation of Cs response: Integral method

- Mean period of the peak grid is calculated. Left/right boundaries of the cell are taken as the position of the first/last peak -/+ half of the period.
- Integral within cell boundaries - I_{center} - as well as integrals below left and right tails - I_{left} , I_{right} - are calculated.
- If cell is in the middle of the calorimeter, both tails are considered to be good and Cs response is:

$$R = (I_{left} + I_{center} + I_{right}) / width$$

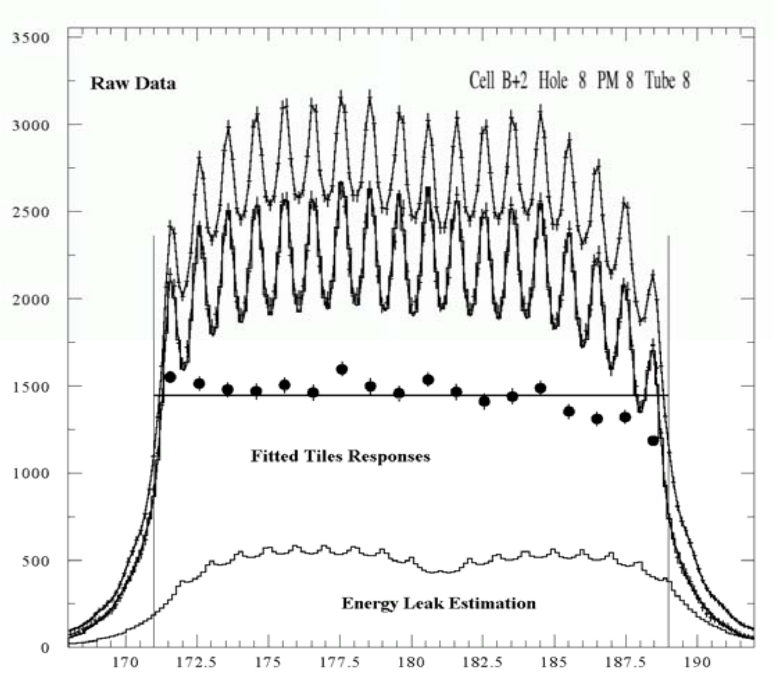


- Accuracy of the method ~ 0.2%
  - Probably there are some systematics for cells at boundaries

Calculation of Cs response: Amplitude method

- Amplitude method allows one to calculate individual tile response
- In this method response is fitted by sum of gaussian + exp. tails for every tile

- Accuracy of single tile response is about 2%, average cell response is known with 0.3% precision
  - Precision of both integral and amplitude methods is better than overall stability of the system



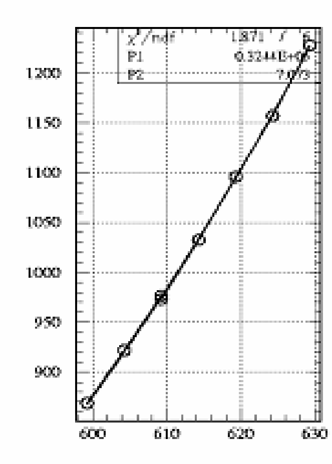
HV equalization

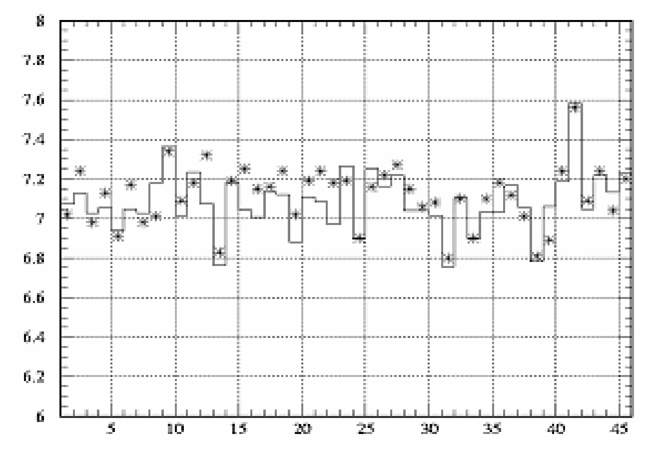
- Cesium system is used for initial equalization of cell responses
- Signals from all the cells are equalized with an iterative procedure, the desired HV is calculated from the formula

$$HV_{new} = HV_{old} \times \left(\frac{Amp_{ref}}{Amp_{meas}} \right)^{1/\beta}$$

- Parameter β is measured for every PMT during quality check, but is good enough just a single value β=7
- Procedure stops after 3rd iteration, when corrections are less than 0.5 V

$$Amp = \alpha \times HV^{\beta}$$





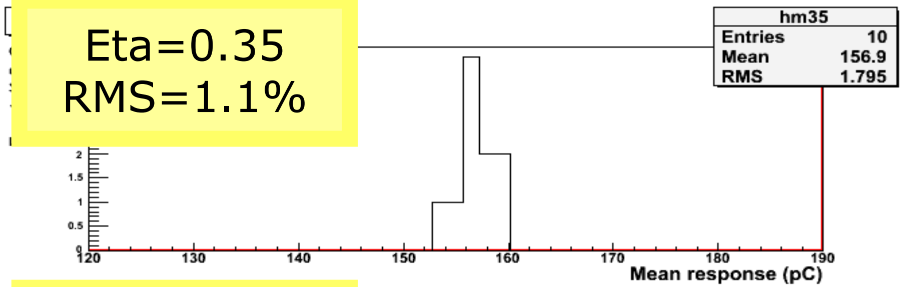
Beta from fit(hist) and QC (stars)

Calorimeter non-uniformity after HV equalization

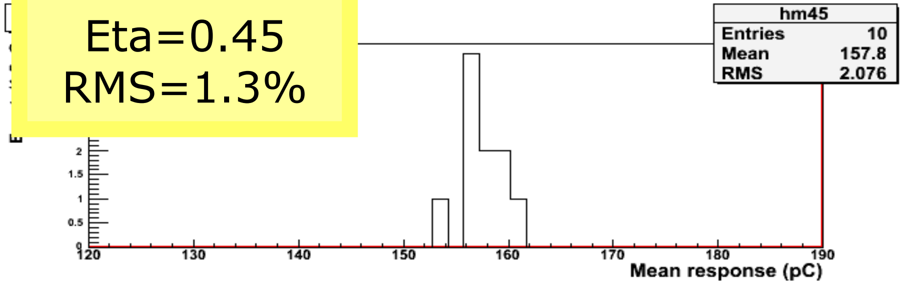
- Overall cell-to-cell non-uniformity of the calorimeter after Cesium equalization as seen by muons and electrons is less than 3%
- It is worse than precision of Cs measurements because muon, electron and Cesium source “see” different part of the cell and scintillating tiles are not identical (5-8% tile-to-tile variation observed during instrumentation)
- Hadronic shower spans over many cells of the calorimeter and non-uniformity of response for single pions is at the level of 1.3%

Calorimeter non-uniformity

Uniformity for pions

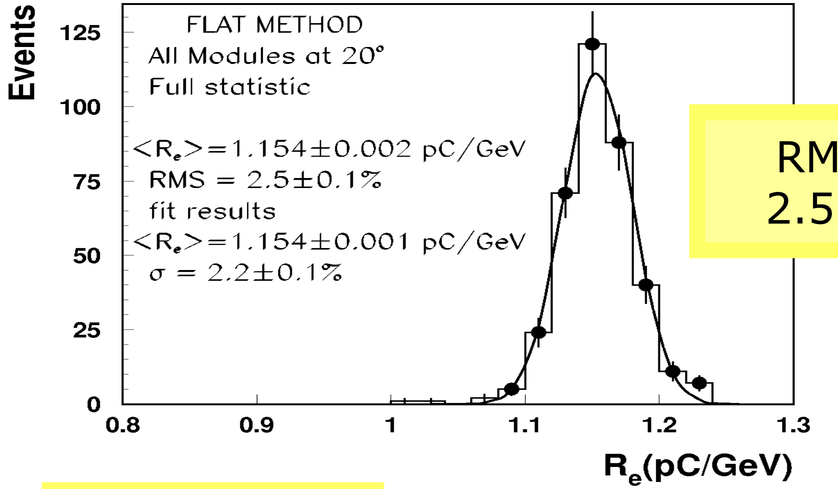


Eta=0.35
RMS=1.1%



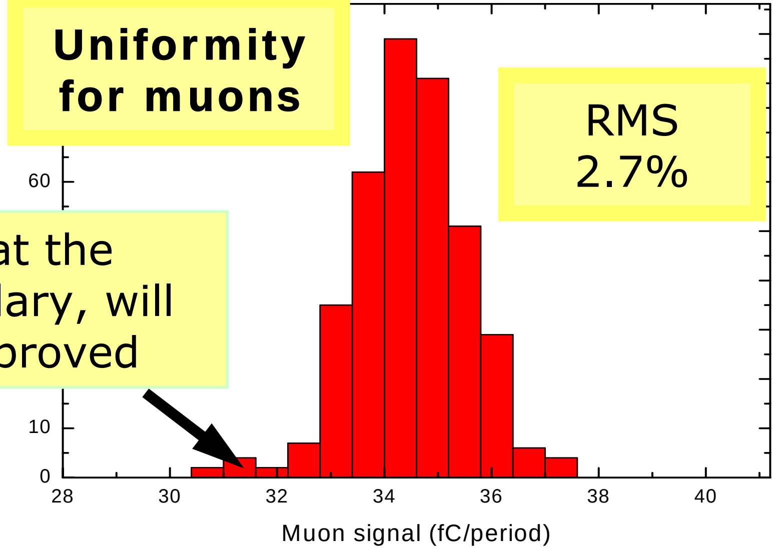
Eta=0.45
RMS=1.3%

Uniformity for electrons



RMS
2.5%

Uniformity for muons

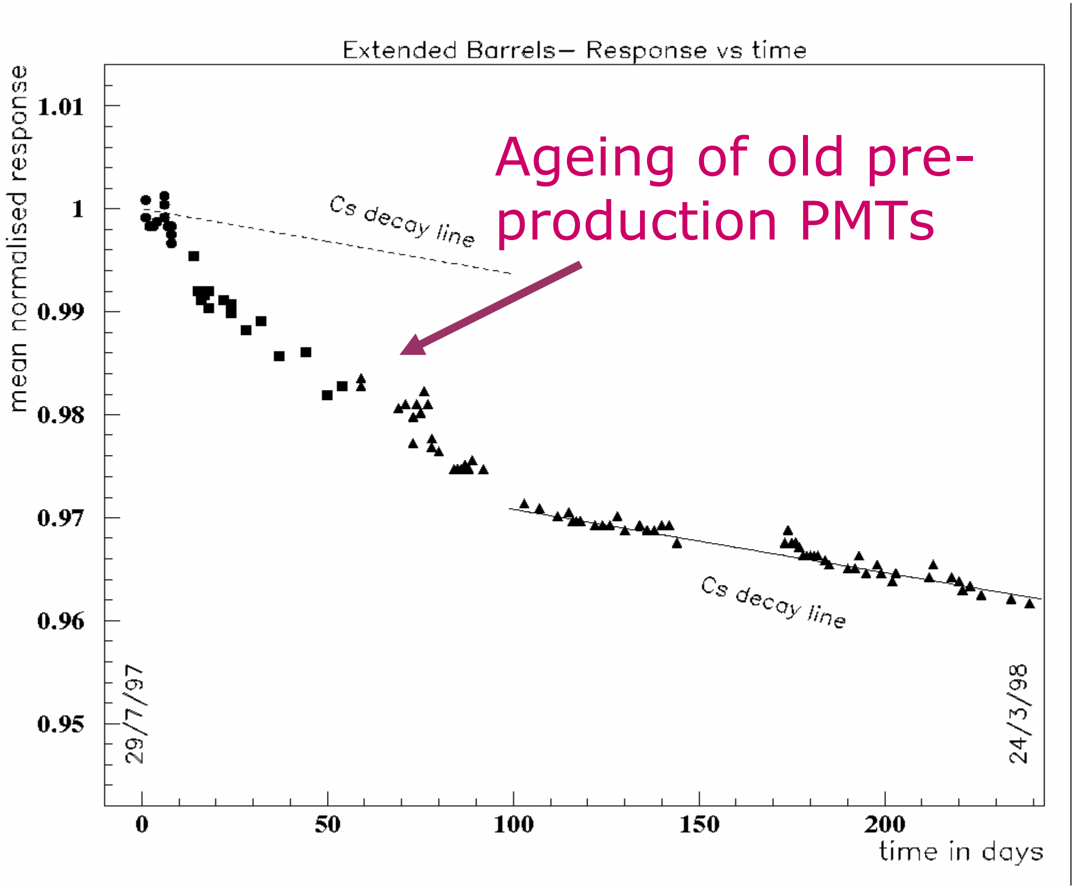


RMS
2.7%

Cells at the boundary, will be improved

Cs monitoring of long-term stability

- Cesium system will be used in ATLAS to monitor long term stability of the calorimeter
- This was done already in 1997 and 1998 when stability of preproduction PMT's were studied
- With Cesium system not only stability of PMT's, but also bad tile-to-fiber coupling and aging effects in scintillator will be detected
- Stability of the PMT's between two Cesium runs will be monitored by Laser system



Ageing of old pre-production PMTs

TileCal monitoring with minimum bias events

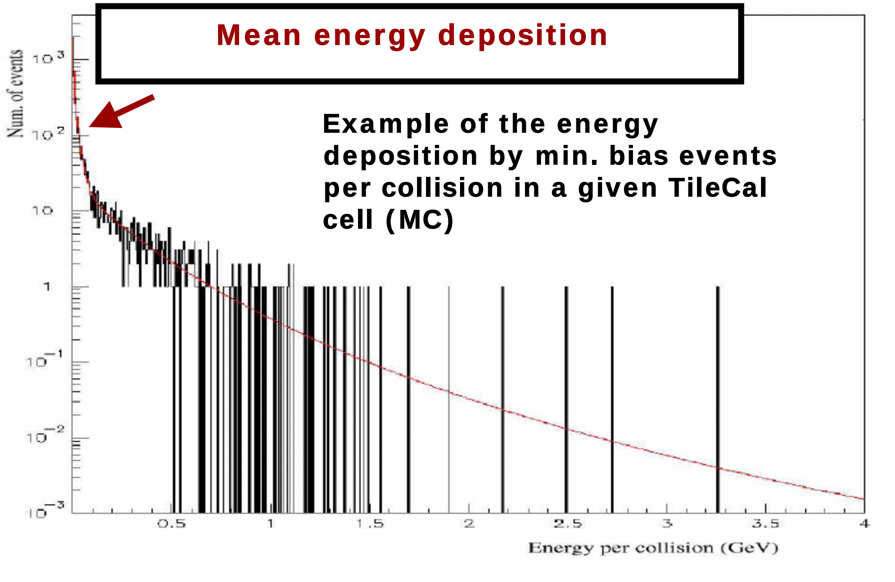
MB events: inelastic pp collisions at low momentum transfer

- Expected 23 MB events per bunch crossing at high luminosity
- Integrated energy is proportional to the LHC luminosity
- Energy distribution is symmetric in ϕ
- Variations over TileCal $\Delta\eta$ are of a factor 10
- Variations between the TileCal samples are of factor of 100

The signal generated in TileCal by the Minimum Bias events will be used to monitor both the TileCal (pC/GeV in cells) and the LHC machine performance (relative luminosity) during data taking

Tile MinBias

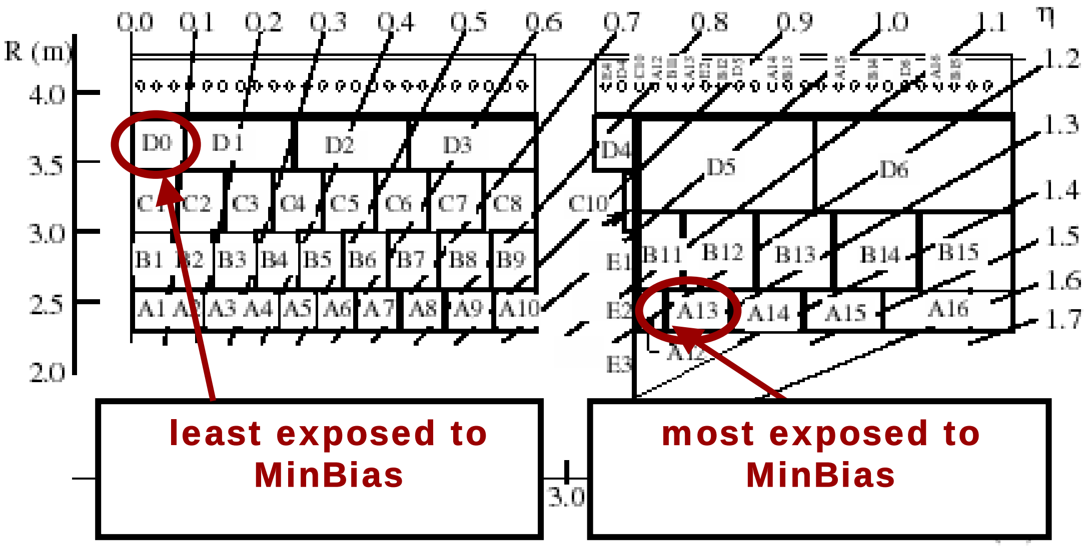
- Typically low-energy forward jets (few hard interactions -> “physics”)
- Large fluctuation of energy deposition in a given cell
- Average MinBias signal spans a broad range of frequencies and amplitudes



Mean energy deposition

Example of the energy deposition by min. bias events per collision in a given TileCal cell (MC)

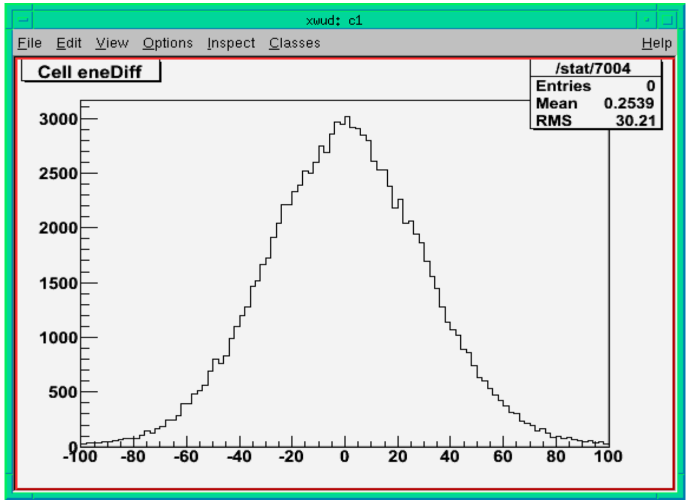
- Slow integration of PMT current (10ms ~ 110 LHC orbits ~400000 BX ~8 M inelastic interactions)
- Monitor each cell/PMT channel) online
- rLuminosity measurement

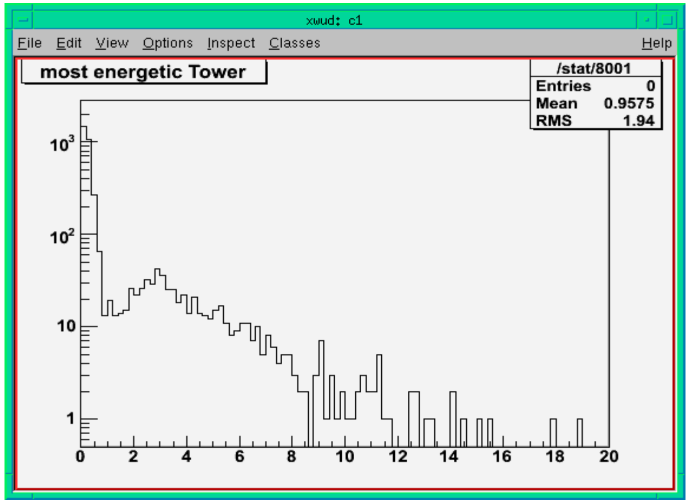


least exposed to MinBias

most exposed to MinBias

TileCal monitoring with Event Filter





A set of needed histograms @ EF :

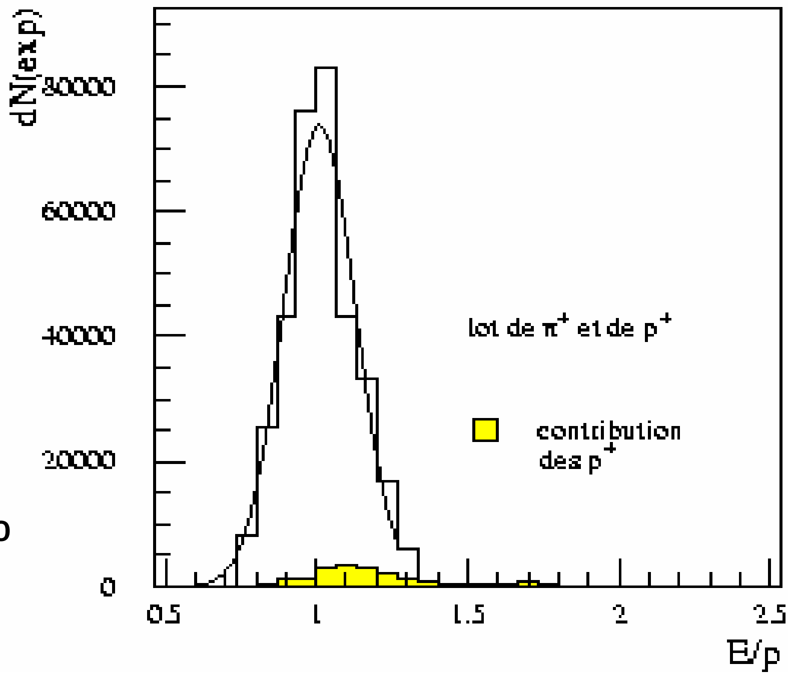
- + Most energetic Tower (1-dim histo & eta-phi)
- + All towers channel-by-cannel
- + All & most energetic cells (E/time diff by PMTs)
- + TileMuID back-to-back objects
- + Noise-per-channel
- + (Fraction of) coherent noise to average noise
- + more possible!

(ATLAS offline software running online)

In-situ calibration strategy for ATLAS

Correct for **detector effects**
Recovery methods: weighting techniques, energy flow method

- Global E/p bias < 0.6 %



Golden channels:

E/p for a single hadron (usually from τ)
with 10 fb^{-1} of data (**one year** of low luminosity, 320k signal events) may reach 0.6% level in jet E calibration

Z/γ+jet pT balance
with 10 fb^{-1} of data may reach 1% level in jet E calibration and 1% linearity

t->Wb->jjb
with 10 fb^{-1} of data may reach 2% level in jet E calibration and 2% linearity

Concerns

limited statistics and huge number of calibration constants (usually both energy and η dependent)

Conclusions (1)

- The Cesium, Laser and Charge Injection calibration systems allow to calibrate and to monitor the Tile Calorimeter response with 0.5-1% precision
- After HV equalization overall cell-to-cell non-uniformity of the calorimeter measured with electron and muon beams is better than 3 %
- Non-uniformity of the calorimeter response for hadronic showers is at the level of 1.0 - 1.5%

Conclusions (2)

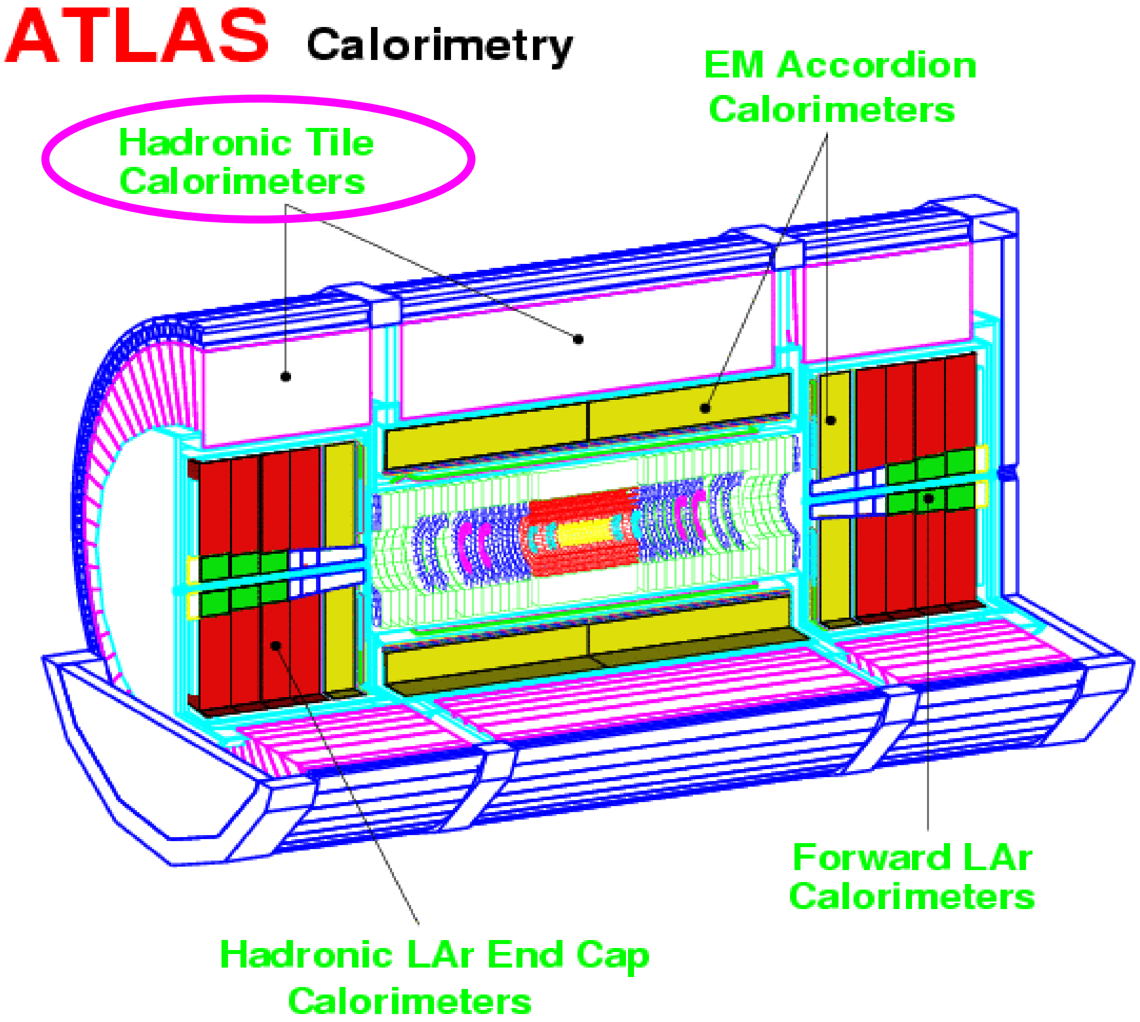
Other important TileCal monitoring systems were not presented in this talk, like the HV and Low Voltage monitoring (Detector Control System) or the Cooling system (for temperature stability)

After the testbeam and the commissioning phase, the different calibration and monitoring systems are ready, and waiting for the first data taking in one year from now

Thank you!

Backup slides

TileCal



Iron – scintillating tiles sampling calorimeter

Resolution: $\frac{\sigma}{E} \approx \frac{50\%}{\sqrt{E}}$

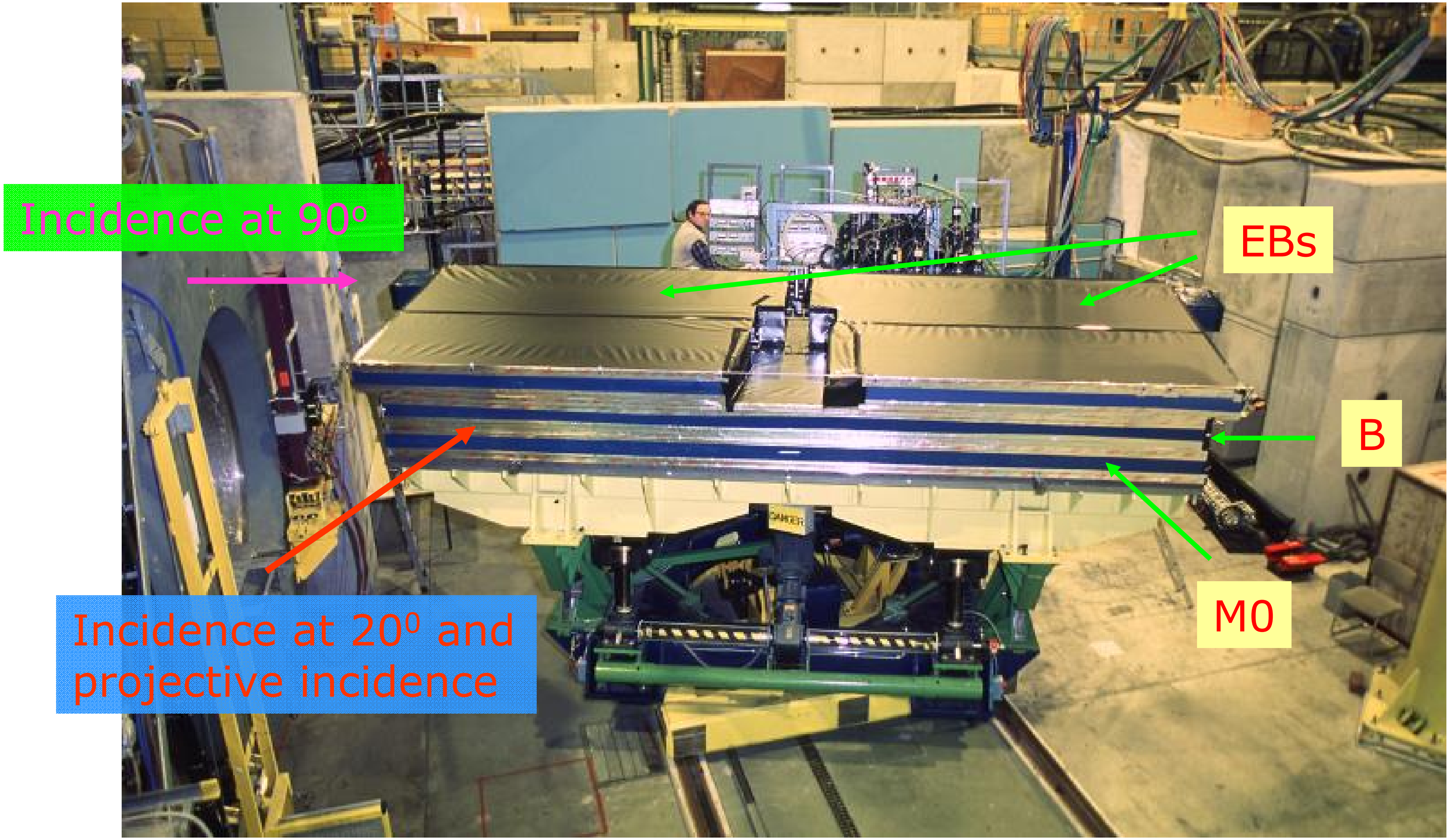
Divided into 3 parts :

- 1 Barrel ($|\eta| < 1$)
- 2 Extended Barrel

  ($0.8 < |\eta| < 1.7$)

Each part consists of 64 wedges

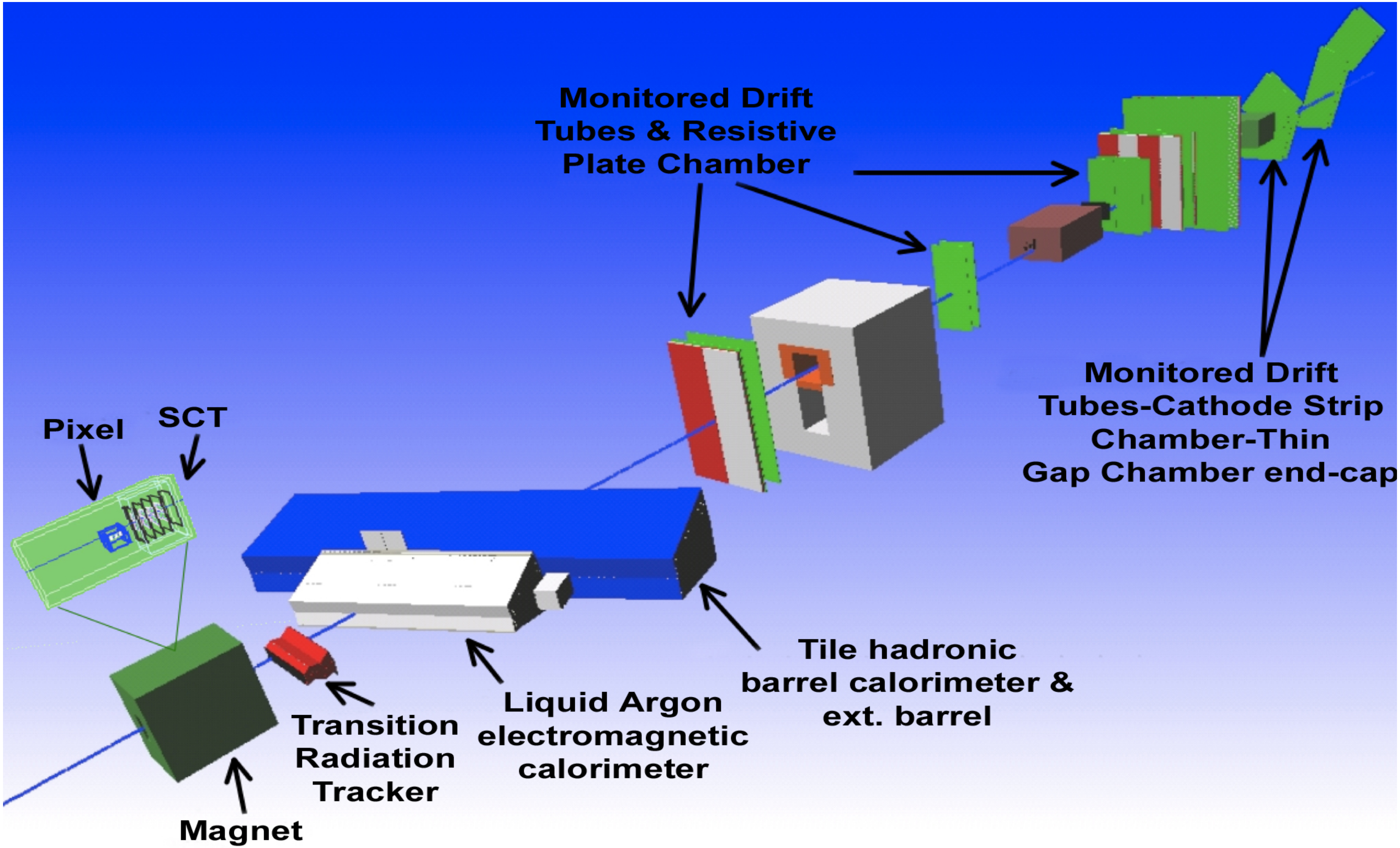
Testbeam setup at H8



Standalone TileCal testbeam

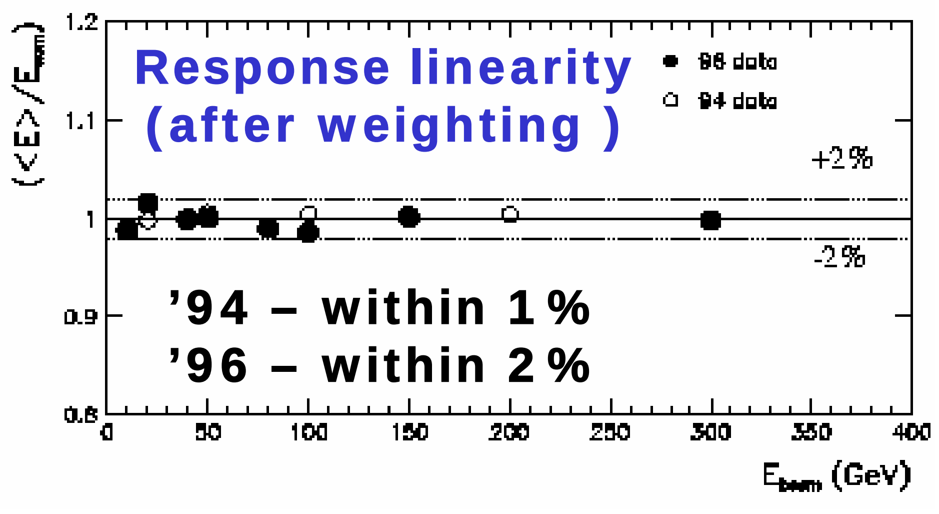
The ATLAS H8 combined testbeam layout in 2004

Test in beam of a slice of ATLAS


Monitored Drift Tubes & Resistive Plate Chamber
Pixel
SCT
Monitored Drift Tubes-Cathode Strip Chamber-Thin Gap Chamber end-cap
Tile hadronic barrel calorimeter & ext. barrel
Liquid Argon electromagnetic calorimeter
Transition Radiation Tracker
Magnet

Tile calorimeter performance for pions

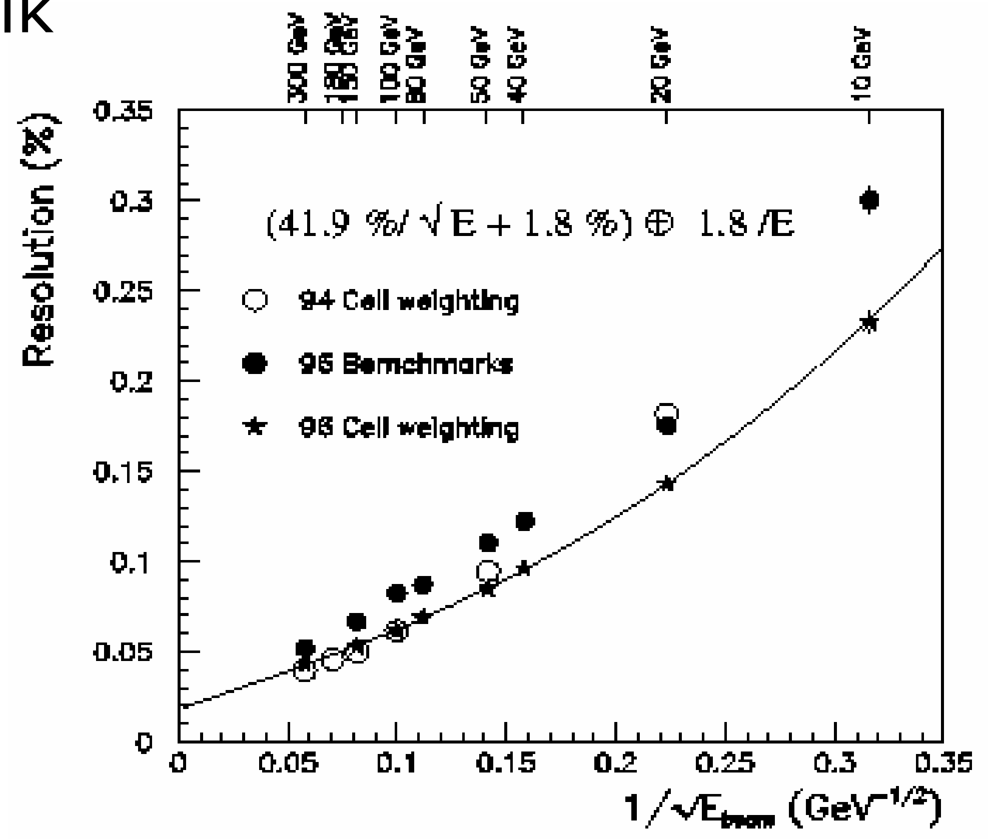
Examples of old (published) testbeam results. More recent results presented in another talk



Response linearity (after weighting)

'94 – within 1%
'96 – within 2%

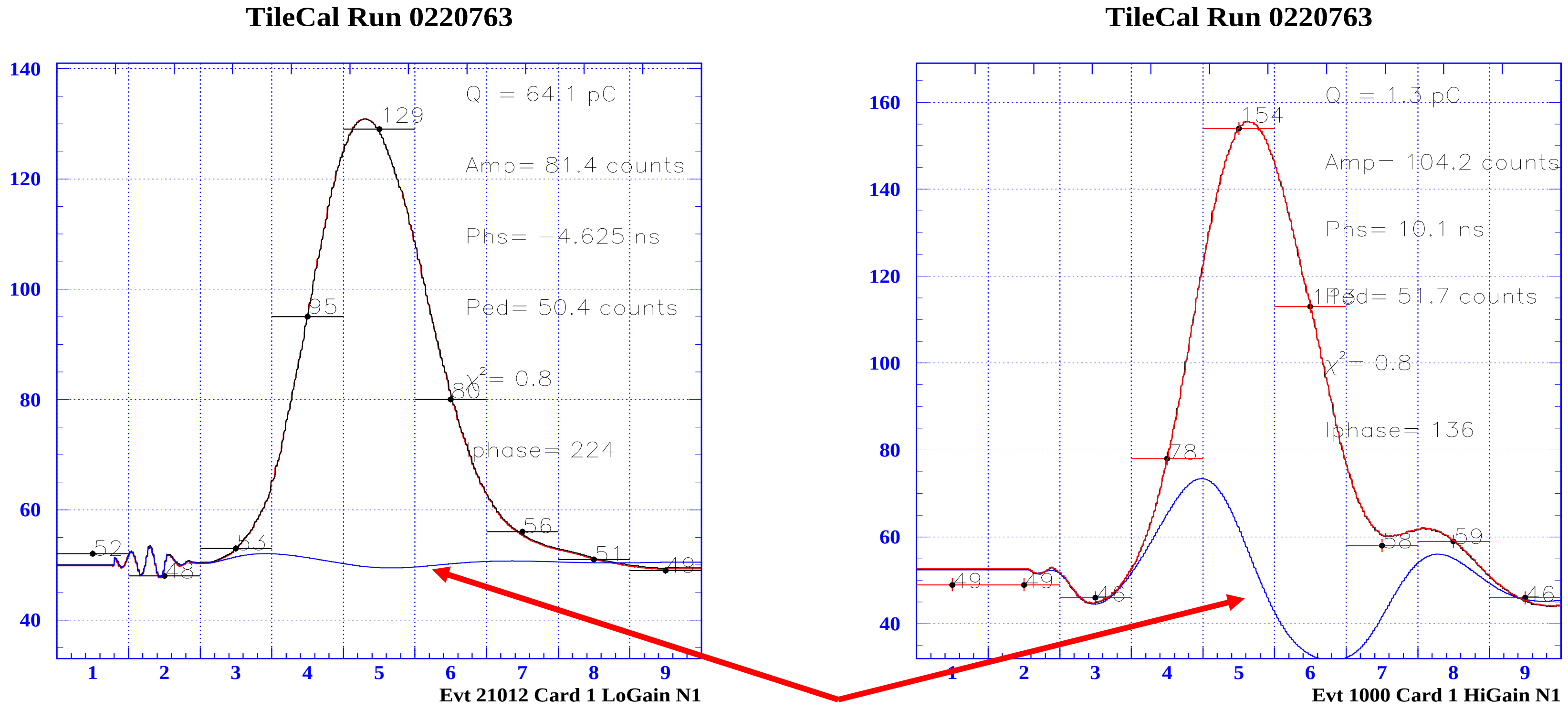
Energy resolution (after weighting)



CIS Fits for Both Gains

Low Gain

High Gain

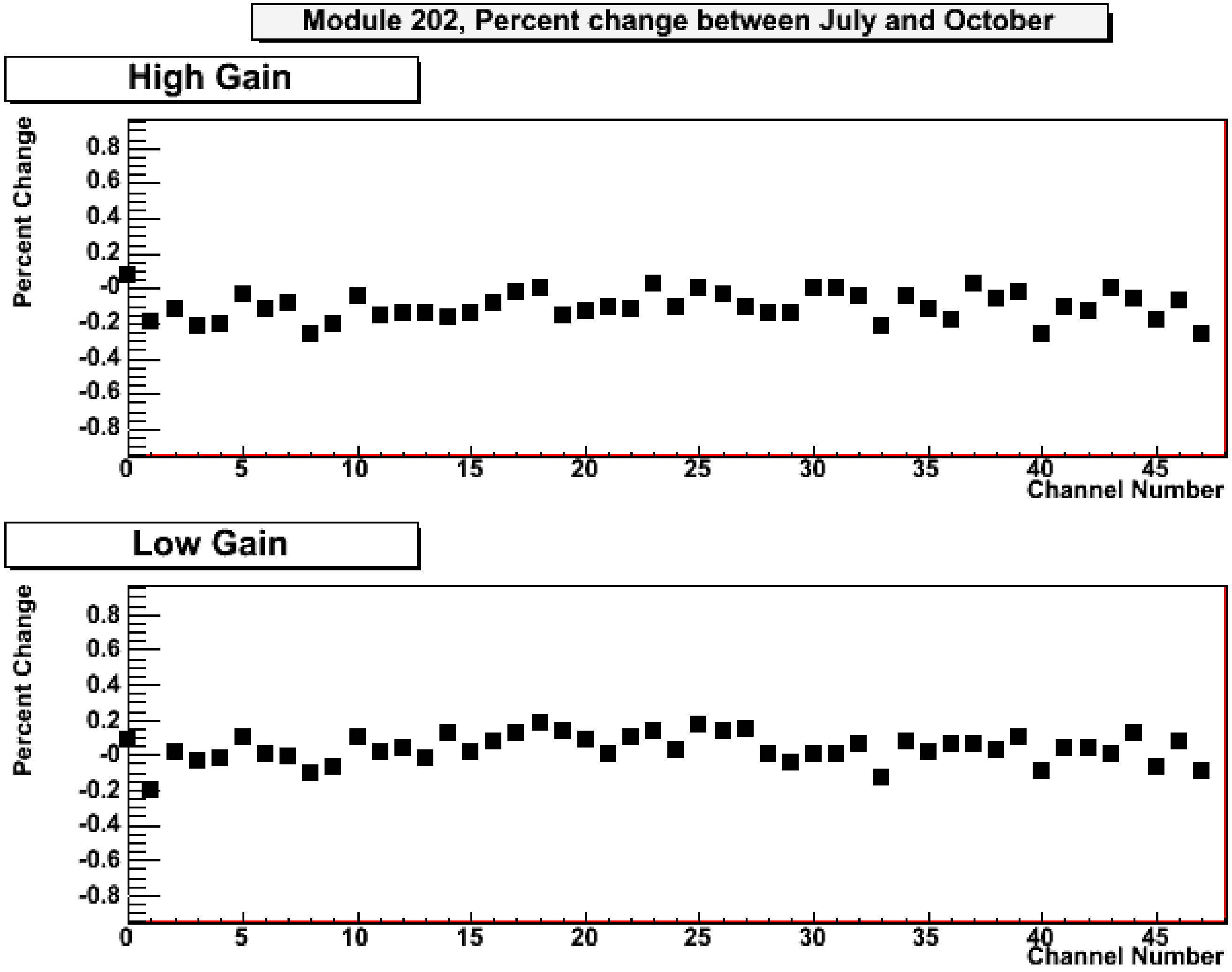


Leakage pulse

Pulse shapes from 2002 but have not changed.

Change in ADC/pC Between July and October '04

Top Module (202, C-side)



CIS summary: constants stable at per-mil level over several months

Old sources (2)

Produced in JINR, Dubna

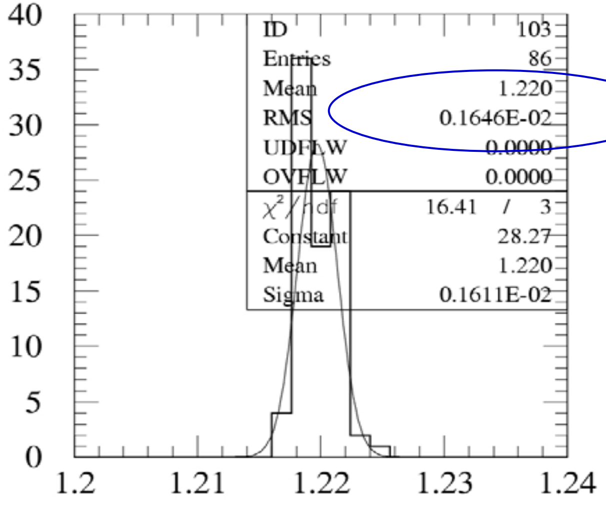
New (3)

Produced by Isotope Products, Prague

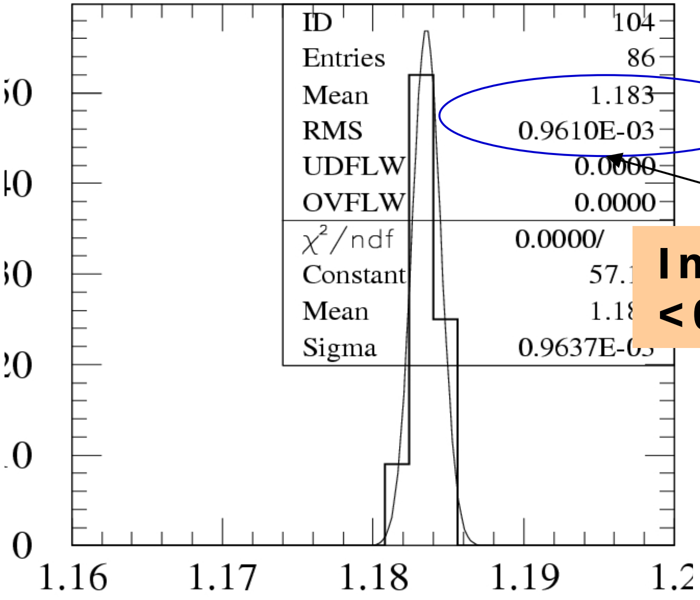
3713RP, ~250 MBq 8 years

3712RP, ~285 MBq 5 years

~350 MBq



3712 vs 3713

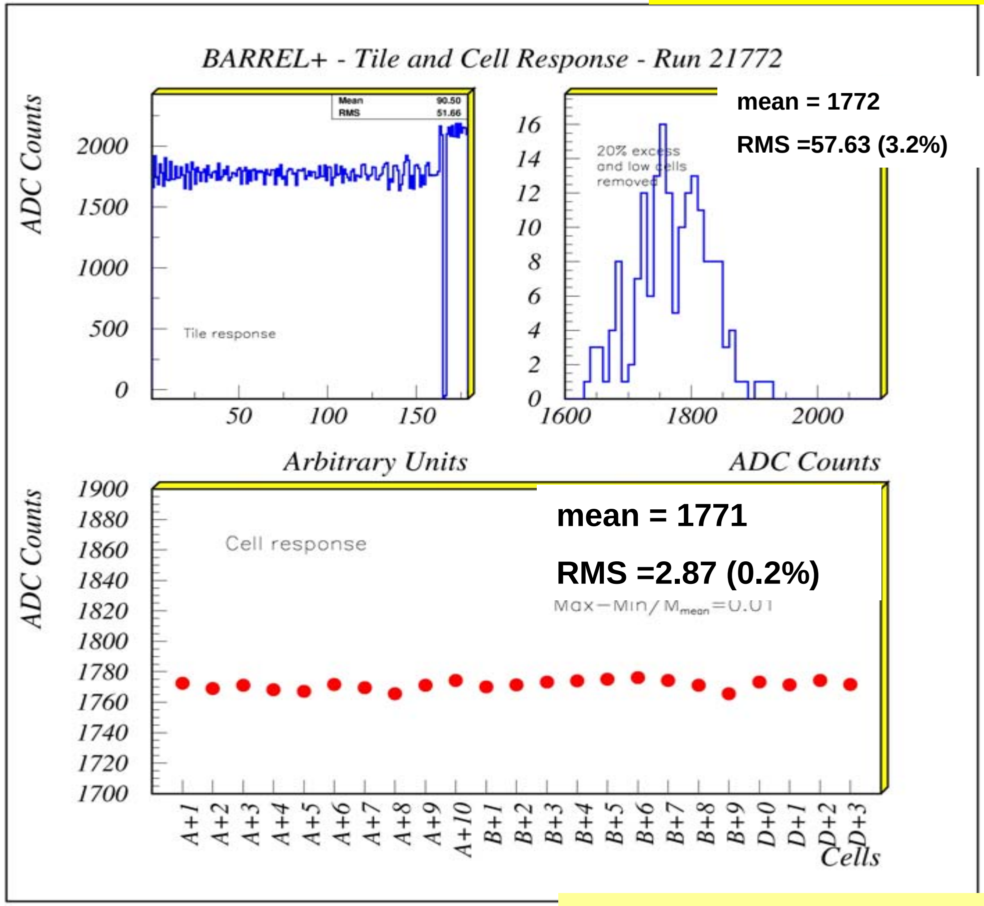


4089 vs 3713

Intercalibration < 0.2 %

Tile and cell uniformity with cesium

Cesium calibration

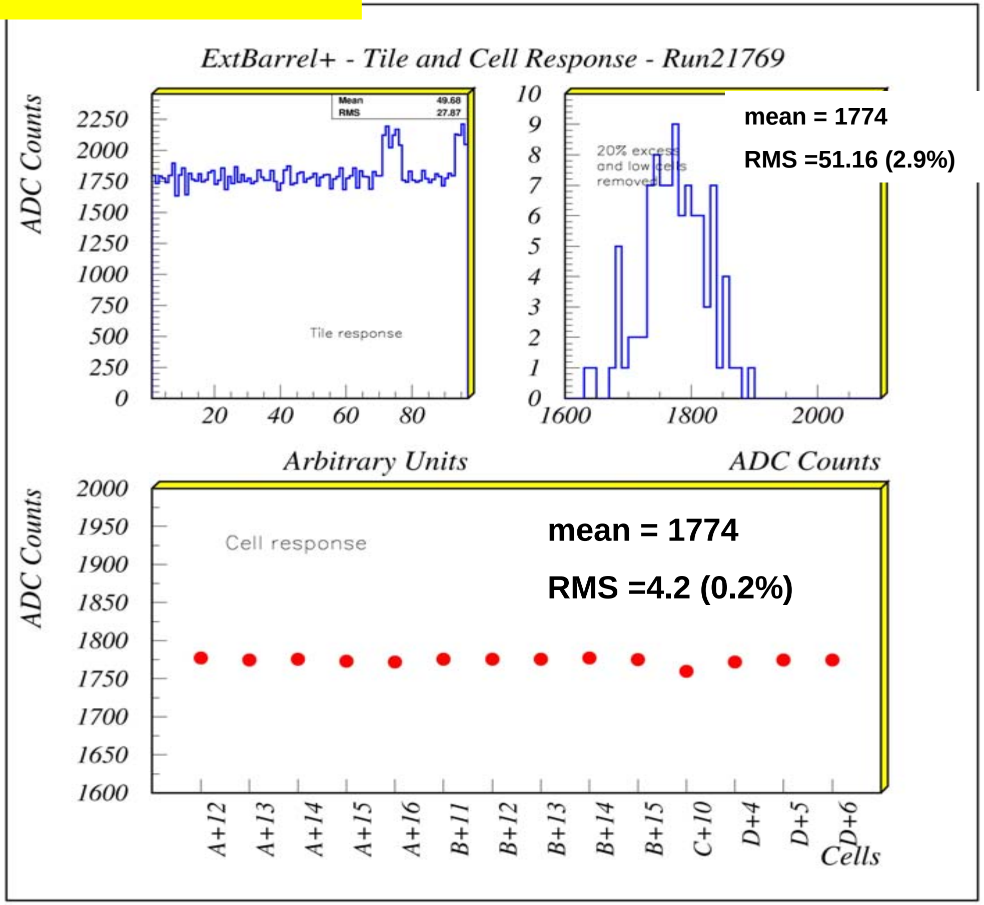

BARREL+ - Tile and Cell Response - Run 21772

mean = 1772

RMS =57.63 (3.2%)

mean = 1771

RMS =2.87 (0.2%)


ExtBarrel+ - Tile and Cell Response - Run21769

mean = 1774

RMS =51.16 (2.9%)

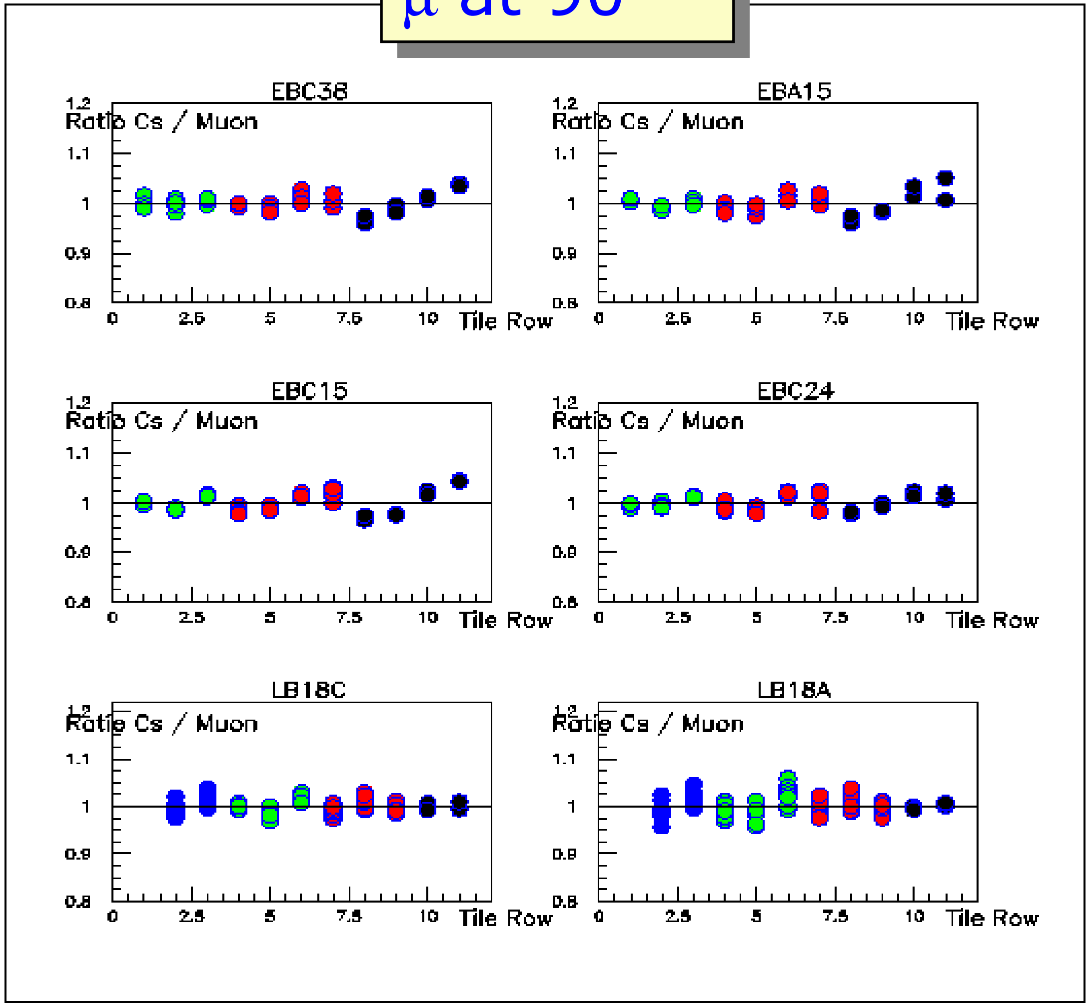
mean = 1774

RMS =4.2 (0.2%)

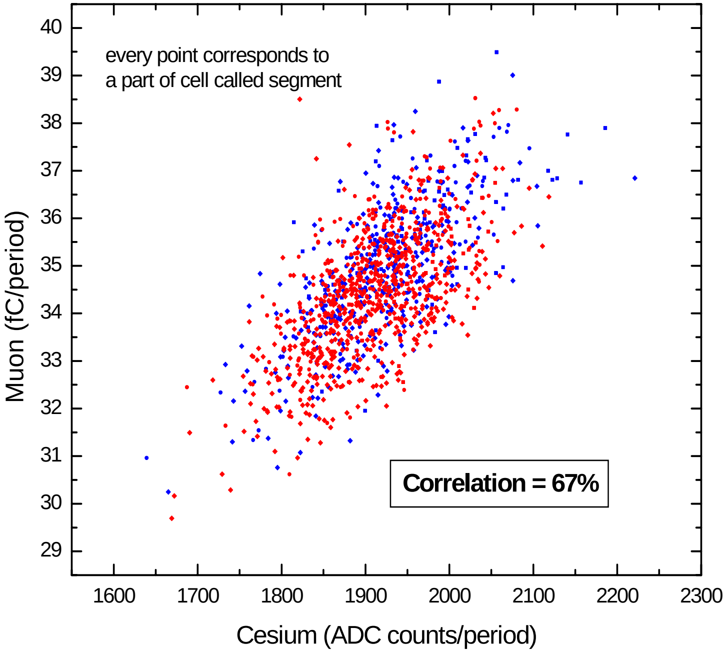
Uniformity: 0.2 %

Comparison between cesium and muons

μ at 90º



Good correlation between Cs and muon response



Data from **334** cells (12 EBs and 5 Barrels).

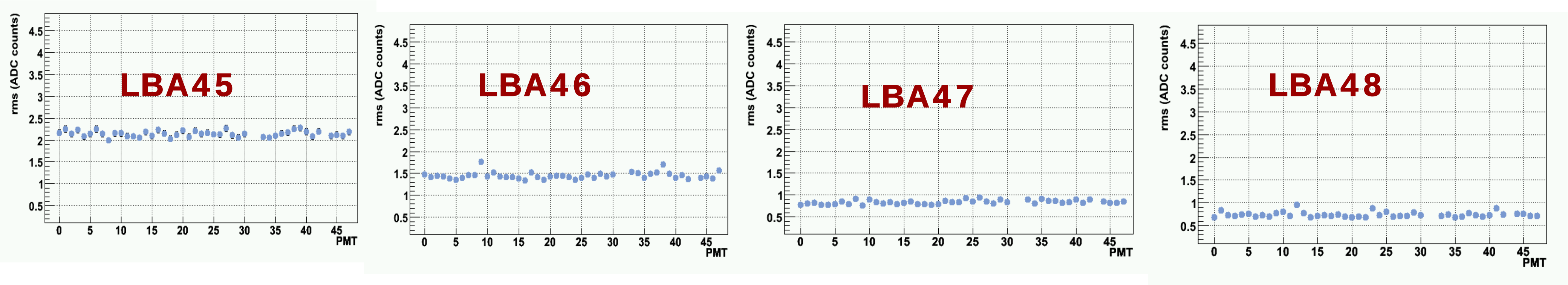
Monitored quantities with Minimum Bias

Item	Quantity	Comments	Estimated #scans over all channels (#sweeps) to reach 1% accuracy
Relative Luminosity	MB current rate	In the selected part of the calorimeter	few
Relative Beam Quality	MB current balance	For example: Ratio of the MB currents in the central and forward parts	tens
TCal cell Perform.	MB current in a given channel	Monitored in time and compared to the similar cells	tens
Monitoring system Perform.	Dead channels, saturation, etc		few

Cell	#measurements per PMT to reach 1% accuracy on PC/GeV ratio
A1	4
A12	27
A16	88
BC1	5
B11	33
B15	9
D0	37
D2	48
D6	4

Pedestal data (run 4 modules in parallel)

- Use pedestal data to validate the MinBias readout
- Characteristic quantity: Channel-by-channel pedestal RMS



- Reference: Well established single-module test-readout (Automated Scan)
- Trigger: ROB, ~95 Hz