ATLAS Tile Calorimeter performance to single particles in beam tests

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Outline

- Introduction to ATLAS/Tilecal and the testbeam program
- Tilecal calibration systems
- Event selection, particle separation
- Corrections applied to data
- EM scale determination
- Pion linearity and resolution
- Conclusions
Tile Calorimeter in ATLAS

- **Tile Calorimeter:**
  - iron/scintillator hadronic calorimeter
  - central region of ATLAS detector ($|\eta|<1.6$), 3 cylinders (1xB, 2xEB)
  - segmentation: 3 radial compartments, $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$ (last layer $0.2 \times 0.1$)

- **Tilecal module ($\Delta\varphi=0.1$)**
  - scintillating tiles staggered in depth, placed perpendicular to colliding beams
  - light collected by WLS fibers, routed to PMTs
  - each cell readout by 2 PMTs
Tilecal in beam tests

- Production modules (final mechanics & electronics) tested in particle beams 2000 - 2003
- Results presented here come from re-calibrated data 2002-2003

Tests in SPS H8-beamline:
- energies from 10 - 350 GeV
- muon, electron and hadron beams
- typical setup (module 0, barrel module, 2 EB modules). The tests included:
  - EM scale settings: shooting electrons into individual cells at 20 deg (all cells of first radial compartment)
  - detector performance "as in ATLAS": particles shot at projective pseudorapidities, entering the centers of the cells
  - special studies at 90 deg: uniformity, hadronic shower profiles, light yield measurement, etc.
Tilescal Calibration Systems (1)

- Charge Injection System (see next pages for more details)
- Laser System:
  - inject pulsed laser light into all PMTs
  - monitors PMT non-linearity and stability

- Cesium System (more details in next page)
- Minimum bias system:
  - signal integration over ~10 msec
  - precise monitoring tool, (relative) luminosity measurement
Tilecal Calibration Systems (2)

- **Cesium System:**
  - passes through individual cells & tiles at 90 deg, signal readout through (slow) integrators
  - can reconstruct individual tile responses (amplitude method)
  - gain of all cells is equalized with Cs by setting the high voltage on the individual PMTs
  - primary tool to set up EM scale (using TB experience): pC/GeV
Tilecal Calibration Systems (3)

- **Charge Injection System (CIS):**
  - injects well defined charge into fast bi-gain electronics
  - provides ADC/pC conversion for both gains
  - offline correction for non-linearity in low-gain
  - uncertainty of mean measured response associated with the ADC performance and the calibration uncertainties: <1%

Impact on the jet energy measurement even smaller since more channels will be involved.
Physics Event Selection

- Beam cuts:
  - require a MIP-like signal in upstream beam scintillators, avoid upstream showering and/or double particle events
  - restrict angular spread and impact point with beam chambers, avoid halo particles with potentially bad energies

- Particle selection criteria:
  - muons taken out using total energy criteria
  - $e/\pi$ separation:
    - exploit average density differences
    - Cherenkov counter info further improves selection for $E_{\text{beam}} \leq 20$ GeV
  - $\pi/p$ separation:
    - positive beams only (50-180 GeV)
    - use of Cherenkov counter
Corrections applied to raw data

- correct for bad PMTs
- correct for bias introduced by particle separation criteria (e.g. average density)
- particle/Cs correction (see next pages)
- longitudinal leakage correction (see next pages)
- correct for real beam energies (calculated from known settings of magnets & collimators in the beamline)
Particle/Cs correction

- Difference particle/Cs:
  - particles at 90 deg entered the tile center, whereas Cs deposits energy at the tile edge.
  - non-uniform tile response across its surface causes systematic particle/Cs difference.
  - evaluate weights for individual radial compartment:
    - $w(1st) = 1$ (preserve EM scale)
    - $w(2nd) = 1/0.975$
    - $w(3rd) = 1/0.922$

Data from 90 deg muons, similar picture obtained with 90 deg electrons

1 event example: 100 GeV $\pi@\eta=0.35$

x $w(1st)$ x $w(2nd)$ x $w(3rd)$
Longitudinal leakage correction

- Want to compare the results with that of radially longer Tilecal prototype modules => scale resulting pion linearity and resolution for an "infinite" calorimeter
- Correction for peak value and resolution obtained from special 90 deg pion studies

Different calo depths

165 cm ~ production modules, $\eta=0.35$
195 cm ~ prototypes, $\eta=0.35$
Setting the EM scale

- EM scale determined with electrons entering at 20 deg
  - 11% of all Tilecal modules brought to beam tests
  - electrons shot in all cells of the first radial compartment
  - averaged over all tested modules, we got: 1.05 pC/GeV

Final:
Mean = 1.05 ± 0.03 pC/GeV
Rms = 2.4 ± 0.1%
Pion results (1)

• Pion response normalized to the beam energy:
  - data from several modules combined; modules are inter-calibrated with \( \pi \) at 180 GeV
  - calorimeter is non-compensated, data in reasonable match with Wigmans' parametrization
    • \( e/h = 1.36 \), result from earlier Tilecal analyses
    - good agreement data vs. MC

• Comparison to earlier Tilecal prototype modules (+30 cm):
  
  Production mods (\( L=\infty \))  Prototypes (\( L=\infty \))
  
  \[ R(180 \text{ GeV}/20 \text{ GeV}) \quad 1.059 \pm 0.005 \quad 1.083 \]

  - recent studies in ATLAS combined testbeam show the same value (1.059±0.008)
Pion results (2)

- Pion energy resolution:
  - data from several modules combined:
    \[ \frac{\sigma}{E} = (52.7 \pm 0.9)\% \sqrt{E} + (5.7 \pm 0.2)\% \]
  - result in good agreement with resolution obtained for prototype modules when accounting for different calorimeter lengths
Conclusions

- Big effort invested into understanding the details of the Tile calorimeter calibration and response to particles.

- The new calibration, involving also the correction for longitudinal leakage, restores the expected pion response curve as a function of energy.

- Reasonable agreement with recent MC.

- The gained experience should allow us to calibrate all 10k Tilecal channels at EM scale in ATLAS within 1-2%