Calibration of the relative response of the ALICE electromagnetic calorimeter EMCAL

Outline

- **Physics motivations:**
  - Quark-Gluon Plasma study
- **The experiment:**
  - The ALICE experiment and its calorimeters
  - EMCAL characteristics
- **Calibration with cosmic muons:**
  - Experimental setup
  - Analysis procedure
  - Results
  - Tracking time variations

Julien FAIVRE for the ALICE collaboration
# The Quark-Gluon Plasma (QGP):

<table>
<thead>
<tr>
<th>Interaction:</th>
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<tbody>
<tr>
<td>Electromagnet.</td>
<td>Strong</td>
<td></td>
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<table>
<thead>
<tr>
<th>Object</th>
<th>Charged particles</th>
<th>Quarks, gluons (partons)</th>
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</thead>
<tbody>
<tr>
<td>Vector</td>
<td>Photon</td>
<td>Gluon</td>
</tr>
</tbody>
</table>

Observable objects are always color-neutral
\[ \Rightarrow \text{partons hadronize: they appear as jets} \]

Large color charge density
\[ \Rightarrow \text{screening} \]
Color deconfinement
\[ \Rightarrow \text{Quark-Gluon Plasma (QGP)} \]

QGP: dense medium, partonic (deconfined), in thermal equilibrium
Why/how study the QGP:

- **Phase transition** predicted by Quantum Chromodynamics calculations (QCD = theory of the strong interaction)
- Large color charge density? Ultra-relativistic heavy ion (e.g. Pb) collisions
  
  Reference experiments: p-p, p-A
- **Study**:
  - Phase diagram of nuclear matter
  - Behavior of the hot and dense matter
  - Test QCD calculations
  - Probe partonic composition of proton and nuclei

- **ALICE**: large experiment dedicated to the heavy ion collisions at **LHC @ CERN**
Some probes which involve calorimetry:

- **Photons:**
  - Reference (unaffected by strong interaction)

- **Thermal photons:**
  - Get QGP temperature

- **Jets, azimuthal correlations between jets and hadrons or γ:**
  - Get QGP density
  - Learn how partons interact in QGP
  - Investigate QGP equation of state
  - Measure the in-medium modification of the parton fragmentation function

- **Heavy flavor (c and b quarks):**
  - Test QCD predictions of smaller in-medium energy loss

- All probes
  - involve a test of QCD calculations
  - provide data to constrain nucleon and nuclei parton content
The calorimeter EMCAL:

Total: $10 \times 1152$ channels
- 10 supermodules
- 1 supermodule = $3 \times 8$ strips
- 1 strip = 12 modules of $2 \times 2$ towers
- Segmentation: $6 \times 6 \text{ cm} (4.5 \text{ m from IP})$
- Acceptance: $-0.7 < \eta < 0.7$, $100^\circ$ in $\varphi$
- Located in front of PHOS

- Shashlik: Pb/scintillator stack with wavelength shifting optical fibers in
- Light collect.: avalanche photodiode (APD)
- LED gain monitoring system
- 8 temperature sensors per SM
- Provides a trigger for Physics

Currently: 4 supermodules installed

- Requirements: $\sigma_E/E < 2 \oplus 15/\sqrt{E}$
- Beam test: $\sigma_E/E = 1.7 \oplus 11.1/\sqrt{E} \oplus 5.1/E$
- Contribution miscalibration: adds in the constant term
Relative calibration with cosmic muons:

Pre-calibrate tower gains before inserting in ALICE

Requirements: dispersion < 10%

- APD gain = function of high voltage (measured)
- Towers have varying efficiencies (e.g. light collection)
- **Aim**: tune APD gains so they compensate for the varying efficiencies
  ⇒ Each tower gives identical response to identical E deposit
- **How**: cosmic muons (permanent and free MIPs)
  
  Take data → Calculate new HV
  
  New HV = f(prev HV; measured vs desired signal amplitude)
Relative calibration with cosmic muons:

Pre-calibrate tower gains before inserting in ALICE
Requirements: dispersion < 10 %

Mean deposited energy: \(\simeq 28 \text{ MeV}\) (equivalent of 300 MeV electrons)

- Experimental bench (side view):
  - Top scintillators
  - Bottom scintillators
  - Third at test
  - Cosmic muon
Isolation cut:

- Want narrow energy distribution
  ⇒ discard cosmics which hit more than 1 tower
  ⇒ discard event when a neighbor tower has some signal
  Isolation cut level limited by noise: 3 ADC

- "Map" of energy deposited by a muon crossing a given tower:

  Scintillator trigger  Isolation cut
“Time of flight” (ToF) cut:

- Experimental bench (front view):

Photomultiplier

Scintillator paddle

- Time difference between both photomultipliers:
Average signal amplitude:

Where the muons deposit energy:

- Oblique muons are cut
  ⇒ muons deposit energy in ≃ a single tower
  ⇒ narrow deposited energy distribution
Average signal amplitude:

- No cuts
- ToF cut
- Isolation cut
- Isol + ToF cuts

Cuts: ToF + scintillator selection
Cuts: isol + signal shape + this tower has the largest signal

- Mean of gaussian fit over distributions with isolation and ToF cuts → average signal amplitude
- Measure average signal amplitude for all towers
- Then iteratively tune high voltages to move all average signal amplitudes to e.g. 16 ADC
Contributions to the width:

\[ \sigma_{\text{tot}} = \sigma_{\text{deposited E}} \oplus \sigma_{\text{EMCAL resol}} \oplus \sigma_{\text{digit}} \oplus \sigma_{\text{temperature}} \oplus \sigma_{\text{other}} \]

\[ \rightarrow \sigma_{\text{tot}} \simeq 14 - 17\% \]
\[ \rightarrow \sigma_{\text{deposited E}} \simeq 12 - 16\% \]
\[ \rightarrow \sigma_{\text{EMCAL resol}} \simeq 3.8 - 4.1\% \]
\[ \rightarrow \sigma_{\text{digitization}} \simeq 1.8\% \]
\[ \rightarrow \sigma_{\text{temperature}} \simeq 1.5 - 3.0\% \]
\[ \rightarrow \sigma_{\text{other}} = \text{electronic noise, signal fit, pedestal subtraction, residual oblique muons, ...} \]

Uncertainty on the measured average signal amplitude:

\[ \sigma_\mu = \frac{\sigma_{\text{tot}}}{\sqrt{N}} \]

- Typical statistical relative uncertainty on the average signal amplitude for a 23-hour run (in %)
  \[ \rightarrow \text{Below the 1 \% level} \]
Relative calibration results:

- Dispersion (width ÷ mean) of average signal amplitudes from all towers:
  - \( \square \) Start with worse than 10 %
  - \( \triangle \) Reach < 2 % in 2-3 iterations

(Temperature rise in the hall)

- 5 iterations: spread keeps going down! ⇒ dominated only by statistics collected and number of iterations
- ⇒ relative calibration provided after 3 iterations is reliable
  → can reach the 1 % level
Tracking the tower gain changes:

- **Temperature sensors**: correlation between 2 sensors gives uncertainty ≃ 0.2°
- Temperature dependence of APD gain $G$:
  \[
  \frac{1}{G} \frac{dG}{dT} \simeq -1.5 \rightarrow -4\%/K
  \]
  ⇒ control of the relative calibration at the < 0.5 % level

- **LED monitoring**: currently under study
  LED pulse illuminates tower and goes to reference APD
  ⇒ real-time monitoring of tower gain changes
# Conclusion:

<table>
<thead>
<tr>
<th>How</th>
<th>Requirem. Status</th>
<th>Limits</th>
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</thead>
<tbody>
<tr>
<td>Pre-calibration</td>
<td>Cosmics &lt; 10 %</td>
<td>∼ 2 % Time</td>
</tr>
<tr>
<td>Online monitoring</td>
<td>LED &lt; 5 %</td>
<td>OK LED statistics</td>
</tr>
<tr>
<td>Offline monitoring</td>
<td>TemperatureParticles ∼ 1 %</td>
<td>OK Sensors accuracy</td>
</tr>
<tr>
<td>Offline calibration</td>
<td>Simu OK Stat, HV digitiz.</td>
<td></td>
</tr>
</tbody>
</table>

- **Relative calibration**:  
  Three 1-night data-taking enough to calibrate 1/3 supermodule to < 2 %
- $\pi^0$ peak in Alice with real data  
  (no further relative calibration)

To be done next:
- Relative & absolute calib. with real data  
  (MIPs, electrons matched with TPC tracks, $\pi^0$)
- Check how well LED and temperature monitoring perform in real situation
- DCAL extension (∼ doubles EMCAL acceptance) : same procedure
BACKUP’s
Convergence of the APD high voltages:

- High voltage digitization: 0.2 V/bit
- Limit on gain calibration: $\simeq 0.5\%$

(Temperature rise in the hall)
APD gain as a function of high voltage:

- $G(V) = A + Be^{kV}$
EMCAL data:

- Tower size (active volume): \( \simeq 6.0 \times 6.0 \times 24.6 \, cm^3 \)
- Tower size: \( \Delta \varphi \times \Delta \eta = 0.0143 \times 0.0143 \)
- Layers: \( 76 \times 1.44 \, mm \) Pb
  \( 77 \times 1.76 \, mm \) scintillator
- Number of radiation lengths: \( 20.1 \, X_0 \)
Expected Physics performance with EMCAL:

- Corrected spectrum
- Systematic uncertainty (uncorrelated)
- Systematic uncertainty (100% correlated)

\( p+p \) at 5.5 TeV
Average \( R=0.4 \)
3 \( \text{pb}^{-1} \)

- \( \frac{dN}{dp_T} \)
- Statistical Error
- Systematical

\( L=10^{20} \text{ cm}^{-2} \text{s}^{-1}, T=10^7 \text{s} \)
- \( \text{pp collision} \)
- \( \text{Pb+Pb} \)
- \( \text{p+p} \)

- 1/ln(1/x)

- \( R_{\text{PbPb}} = R_{\text{pp}} \)