Performance of calorimeters in ALICE

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EMCal and DCal represent one detector, hereafter referred to as “EMCal"
Physics with ALICE calorimeters

- PHOS is designed to study thermal properties of hot QCD matter created in AA collisions via measuring direct photon yield.
- Other subjects to study with PHOS: precise neutral meson and direct photon spectra, photon-hadron correlations in pp, pA and AA collisions.
- EMCal due to its large acceptance but less granularity is suitable to study parton energy loss in hot QCD matter via measuring jet spectra.
- EMCal provides reconstruction of neutral fraction of jets.
- EMCal also studies direct photons at high $p_T$, electrons, neutral mesons, photon-jet correlations in pp, pA, AA collisions.
## ALICE calorimeters

<table>
<thead>
<tr>
<th></th>
<th><strong>EMCal/DCal</strong></th>
<th><strong>PHOS</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Active element</strong></td>
<td>Sampling 77 layers (1.44 mm Pb, 1.6 mm Sci) with WSF light collection</td>
<td>Homogeneous crystals PbWO$_4$</td>
</tr>
<tr>
<td><strong>Moliere radius</strong></td>
<td>3.2 cm</td>
<td>2.0 cm</td>
</tr>
<tr>
<td><strong>Photodetector</strong></td>
<td>APD 5x5 mm$^2$</td>
<td>APD 5x5 mm$^2$</td>
</tr>
<tr>
<td><strong>Depth</strong></td>
<td>20$X_0$</td>
<td>20$X_0$</td>
</tr>
<tr>
<td><strong>Acceptance</strong></td>
<td>EMCal: $</td>
<td>y</td>
</tr>
<tr>
<td></td>
<td>DCal: 0.22&lt;$</td>
<td>y</td>
</tr>
<tr>
<td><strong>Granularity</strong></td>
<td>Cell 6x6 cm$^2$, $\Delta \varphi \cdot \Delta \eta =0.0143 \cdot 0.0143$</td>
<td>Cell 2.2x2.2 cm, $\Delta \varphi \cdot \Delta \eta =0.0048 \cdot 0.0048$</td>
</tr>
<tr>
<td><strong>Modularity</strong></td>
<td>EMCAL: 10+2(1/3) modules</td>
<td>3+1/2 modules</td>
</tr>
<tr>
<td></td>
<td>DCAL: 6(2/3)+2(1/3) modules modules</td>
<td>12544 cells</td>
</tr>
<tr>
<td></td>
<td>17664 cells</td>
<td></td>
</tr>
<tr>
<td><strong>Dynamic range</strong></td>
<td>0-250 GeV</td>
<td>0-100 GeV</td>
</tr>
<tr>
<td><strong>Energy resolution</strong></td>
<td>$\sigma_E/E = 4.8%/E \oplus 11.3%/\sqrt{E} \oplus 1.7%$</td>
<td>$\sigma_E/E = 1.8%/E \oplus 3.3%/\sqrt{E} \oplus 1.1%$</td>
</tr>
<tr>
<td><strong>Distance from IP</strong></td>
<td>428 cm, 0.7-0.9$X_0$</td>
<td>460 cm, 0.2$X_0$</td>
</tr>
</tbody>
</table>
PHOS and EMCAL components

4 EMCAL cells bound in 1 module

PHOS cell – crystal + APD

EMCal+DCal+PHOS layout

PHOS crystal matrix
Trigger system

ALICE calorimeters provide triggers of levels L0 (1.2 μs) and L1 (7 μs).

- **EMCal and PHOS L0**: trigger on 4x4 clusters within trigger region units with energy sum above a threshold
- **PHOS L1**: trigger on photons with 3 thresholds.
- **EMCal L1**:
  - trigger on photons with 2 thresholds.
  - Trigger on jets with 2 thresholds which can cope with uncorrelated background for jets in Pb-Pb

- Thresholds are adjustable depending on collision rate, trigger rejection factor, readout time.

- **Typical thresholds**:
  - 2.5-9 GeV for photon L0 and L1 triggers
  - 16-20 GeV for L1 jets

- J.Kral et al., L0 trigger for the EMCal detector of the ALICE experiment, NIM. A693 (2012) 261-267
- O.Bourrion et al., The ALICE EMCal L1 trigger first year of operation experience, JINST 8 (2013) C01013
Trigger performance

EMCal L1 triggers are bootstrapped:

Triggers with higher rejection factor are treated w.r.t. triggers with low rejection factor.

In pp collisions, only PHOS L0 trigger is enough due to low trigger rate.

In Pb-Pb collisions, L1 triggers become effective.
Energy calibration

- Pre-calibration: voltage is adjusted in every APD to provide the same gain → \( \pi^0 \) peak visible.
- In-situ calibration with physics data by \( \pi^0 \) mass per-cell equalization:
  - High statistics is needed: \( \sim 100M \) events triggered by calorimeters \( \sim \) months of data taking.

Further improvement of calibration is correction for non-linear response of calorimeters
- Simulations do not reproduce all detector effects.
- Only data-driven algorithms are reliable:
  - Test-beam data;
  - Dependence of reconstructed \( \pi^0 \) mass on \( p_T \);
  - Dependence of electron \( E/p \) ratio on \( p_T \).
Timing calibration

- Front-end electronic parameters:
  - Rather long integration time: 2 μs for EMCAL and 4 μs for PHOS.
  - FEE sampling clock: 10 MHz (100 ns) is synchronized with LHC clock 40 MHz (25 ns), but phase remains unknown.
- Minimal bunch crossing (BC) interval at LHC is 25 ns.
- Good timing calibration is important to discriminate photons produced in triggered BC and in the following BCs (out-BC pileup).

Timing calibration is based on physics data
Photon identification

Photon identification in EMCal and PHOS is implemented by two criteria:

- Shower shape
- Anti-track matching

**Shower shape**

**Anti-track matching**

Neutral meson measurements

- For ALICE calorimeters, neutral meson measurements is one of the primary task prior to a more elaborated analysis (direct photons, electrons, jets).
  - $\pi^0$ and $\eta$ are dominant source of background for direct photons;
  - $\pi^0$ and $\eta$ are sensitive probes to study hard parton energy loss in QCD medium via $R_{AA}$;
  - $\pi^0$ and $\eta$ in pp collisions can be measured over much wider $p_T$ range than any other identified hadrons → study QCD in vacuum and thus be used for tuning QCD parameters;
  - $\pi^0$ and $\eta$ are also a good tool for calorimeter calibration due to their large cross sections.

- EMCal and PHOS, complemented by ALICE central tracking system, measure differential yields of neutral mesons in mid-rapidity in all collision systems.
Neutral mesons in pp collisions

Invariant mass spectra of photon pairs and combinatorial background subtraction

Due to low detector occupancy, photon identification criteria are minimal.

At $p_T = 50$ GeV/c decay photons from $\pi^0$ are separated by 1 cell in PHOS:

- It is a limit of invariant-mass analysis.

For EMCAL, this limit is $p_T = 20$ GeV/c.

$\pi^0$ at higher $p_T$ can be measured using shower shape analysis.
Neutral mesons in Pb-Pb collisions

Detector occupancy in central Pb-Pb collisions is high →

- Large combinatorial background;
- Cluster overlap;
- Signal extraction becomes challenging.

Photon identification is applied:

- shower shape to select electromagnetic showers;
- Anti-track matching to select neutral clusters.
EMCal and PHOS already contributed to ALICE measurements of $\pi^0$ and $\eta$:
- pp at $\sqrt{s}=0.9, 2.76, 7, 8$ TeV
- p-Pb at $\sqrt{s_{NN}}=5.02$ TeV (Run1)
- Pb-Pb at $\sqrt{s_{NN}}=2.76$ TeV

Ongoing analyses:
- pp at $\sqrt{s}=5.02, 13$ TeV
- p-Pb at $\sqrt{s_{NN}}=5.02$ TeV (Run2)
- p-Pb at $\sqrt{s_{NN}}=8.16$ TeV
- Pb-Pb at $\sqrt{s_{NN}}=5.02$ TeV

High-$p_T$ range of measurements with neutral mesons (0.8-35 GeV/c) is unbeatable compared to identified charged hadrons.
Electrons are identified with high purity in calorimeters by E/p ratio in conjunction with tracking system via dE/dx.

Due to wide acceptance and trigger on high-energy electrons, EMCal contributes to electron measurements at high $p_T$ with high integrated luminosity.

Electrons from HF decays

Electrons from J/ψ decay

J/ψ yield at |y|<0.9 as a function of dN_{ch}/dη.

p_T=8-11, 11-30 GeV/c from EMCal analysis
Jets

One of the goals of EMCal is to trigger on jets and to measure neutral energy of jets.

Jet neutral energy fraction (NEF) in pp at \( \sqrt{s}=2.76 \text{ TeV} \) is 0.3-0.4 with slight jet energy dependence.


Summary

- ALICE electromagnetic calorimeters contribute to ALICE physics program with photon, neutral meson, electron, jet measurements in pp, pA and AA collisions.
- Trigger system of calorimeters allows ALICE to enhance collected data of event samples with observables of interest.
- Calorimeters are calibrated using the same data used for physics measurements.
- Photon, neutral pion and electron identification is elaborated towards high purity and efficiency.
Backup slides
Readout system

- EMCAL and PHOS have unified readout system:
- Scintillator light is collected to photodetector: APD 5x5 mm²;
- APD signal pass to preamplifier and shaper;
- Signals are digitized by sampling ADC ALTRO and pass to scalable readout units (SRU) via 20-Mb/s p2p links.

Readout time: 172 μs independent from event size.

[F. Zhang et al./NIM A735(2014)157-162]