The PHoton Spectrometer (PHOS) of the ALICE experiment

Per Thomas Hille for the ALICE PHOS collaboration

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2 The ALICE PHOS detector

3 results

4 Current status an plans
Results from RHIC

- \( p+p \) at \( \sqrt{s} = 200 \text{GeV} \)
  - NLO pQCD calculations describe \( \pi_0 \) spectra

- Central Au + Au collisions at \( \sqrt{s} = 200 \text{GeV} \)
  - Nuclear modification factor
    \[
    R_{AA}(p_T) = \frac{d\sigma/dp_T}{<\sigma_{inel} T_{AA}>} \frac{d\sigma_{pp}/dp_T}{d\sigma_{pp}/dp_T}
    \]
  - Huge suppression for light mesons
  - No suppression for direct \( \gamma \) (Except possible isospin effects at very high \( p_T \))

- Conclusion: De-confined opaque partonic matter in central Au + Au collisions

**PHENIX preliminary**

**PHENIX Preliminary PbPb & PbSc**

- Direct \( R_{AA} \), 0-10%
- \( <\sigma_{inel} T_{AA}> \)
- \( R_{AA} \) 9-10%
- \( R_{AA} \) 0-10%


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**The PHoton Spectrometer (PHOS) of the ALICE experiment**
LHC

- Four main experiments: ATLAS, LHCb, CMS and ALICE
- $\sqrt{s} = 14\,\text{TeV}$ for $p+p$ and $\sqrt{s} = 5.5\,\text{TeV}$ for $\text{Pb} + \text{Pb}$
- Energy = 30xRHIC
  - Higher temperature
  - Longer lifetime of the QGP
  - Better background photon suppression

<table>
<thead>
<tr>
<th>run time $T$</th>
<th>$\mathcal{L}$, $\text{cm}^{-2}\text{s}^{-1}$</th>
<th>$\mathcal{L}T$, $\text{nb}^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 days</td>
<td></td>
<td>13</td>
</tr>
<tr>
<td>1 month</td>
<td>$5 \cdot 10^{28}$</td>
<td>130</td>
</tr>
<tr>
<td>3 months</td>
<td></td>
<td>390</td>
</tr>
</tbody>
</table>

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ALICE Observables

- Multiplicity
- Particle spectra
- Particle correlations
- Event by event fluctuations
- Jets
- Direct photons and light neutral mesons ($\pi_0$ and $\eta$)
- Di-leptons
- Heavy-quark and quarkonium production

PHOS potential

- $\pi_0$ and $\eta$ up to 70 - 80 GeV
- Direct photons up to 40 - 50 GeV
- Hadron - $\gamma$ correlations together with EMCAL and TPC

Figure: Photon detectors in ALICE
The PHoton Spectrometer (PHOS) of the ALICE experiment
## Comparison of calorimeters at ATLAS, CMS and ALICE

<table>
<thead>
<tr>
<th>Experiment</th>
<th>ATLAS</th>
<th>CMS</th>
<th>ALICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>LAr Barrel</td>
<td>ECAL(EB)</td>
<td>PHOS</td>
</tr>
<tr>
<td>Detection</td>
<td>Liquid Ar</td>
<td>PWO + APD</td>
<td>Pb + APD</td>
</tr>
<tr>
<td>Coverage</td>
<td>(0 &lt;</td>
<td>\eta</td>
<td>&lt; 1.4) (2\pi)</td>
</tr>
<tr>
<td>Granularity</td>
<td>0.003x0.100</td>
<td>0.0174x0.0174</td>
<td>0.004x0.004</td>
</tr>
<tr>
<td>(\Delta \eta \Delta \varphi)</td>
<td>0.025x0.025</td>
<td>0.025x0.050</td>
<td>0.0143x0.0143</td>
</tr>
<tr>
<td>E. Res</td>
<td>10% / (\sqrt{E}) (\oplus 0.5)%</td>
<td>2.7% / (\sqrt{E}) (\oplus 0.55)%</td>
<td>3.3% / (\sqrt{E}) (\oplus 1.1)%</td>
</tr>
</tbody>
</table>

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PHOS requirements

Physics requirements

- Detection of direct photons > 5 GeV
- Rejection of charged particles
- $\pi^0$ and $\eta$
  - 100 MeV - 30 GeV: two photon invariant mass
  - > 30 GeV: Shower topology
- $\gamma$ vs $\bar{n}n$ annihilation: TOF
- Discrimination of $\gamma$ and hadrons: Shower topology
- Separation of Direct and Thermal photons: Estimated by p+p measurements scaled to A+A

Detector requirements

- Large dynamic range: 5 MeV - 100 GeV
- Good TOF resolution: less than 1 ns at 2 GeV
- Good energy resolution: $\sim 3%/\sqrt{E}$ (E in GeV)
- Good spatial resolution:
  \[ \sigma_x (mm) = \sqrt{\frac{3.26^2}{E} + 0.44^2} \]
The ALICE PHoton Spectrometer (PHOS)

17920 detection channels of \( PbWO_4 \) crystals segmented in 5 modules of 64x56 crystals. Each crystal is equipped with and Avalanche Photo Diode (APD, Hamamatsu S8148/S8664-55) and Charge Sensitive Preamplifier (CSP). The crystals are operated at -25 degrees which increases the light yield by a factor 3 compared to room temperature.

<table>
<thead>
<tr>
<th>Properties of the ( PbWO_4 ) crystal</th>
<th>Properties of the APD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>Q. E</td>
</tr>
<tr>
<td>( 8.28 g/cm^3 )</td>
<td>60% – 80%</td>
</tr>
<tr>
<td>Radiation length</td>
<td>Area</td>
</tr>
<tr>
<td>0.89 cm</td>
<td>5x5 mm(^2)</td>
</tr>
<tr>
<td>Interaction length</td>
<td>Peak Wavelength</td>
</tr>
<tr>
<td>19.5 cm</td>
<td>600 nm</td>
</tr>
<tr>
<td>Moliere radius</td>
<td>Capacitance</td>
</tr>
<tr>
<td>2.0 cm</td>
<td>80 pF</td>
</tr>
<tr>
<td>Dimension</td>
<td>Photo-sensitivity</td>
</tr>
<tr>
<td>2.2x2.2x18 cm</td>
<td>0.24 A/W at peak</td>
</tr>
</tbody>
</table>

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First PHOS physics: inclusive $\pi^0$ spectrum in $pp$


Detection rate of $\pi^0 \rightarrow \gamma\gamma$ in PHOS

Inclusive $\pi^0$ spectrum can be measured in 3 PHOS modules within 3 days up to $p_T = 15$ GeV/c with ALICE minimum bias trigger and up to 25 GeV with PHOS L0 trigger.
The PHoton Spectrometer (PHOS) of the ALICE experiment

(a) PHOS
(b) One PHOS module
(c) Structure

(d) Thermo casing
(e) Strip unit
(f) Mounting

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The PHoton Spectrometer (PHOS) of the ALICE experiment

Outline
introduction

The ALICE PHOS detector
results
Current status an plans

(g) Left: APD, Right: CSP

(k) T-Card with one APD+CSP connected

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Outline

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(l) PHOS-2 from front
(m) PHOS-2 from back
(n) Hardware components
Front end electronics

Readout board
- 32 ch dual gain $2\mu$s shapers
- Noise: $\sim 600e^- = 3.1$ MeV
- 14 bit dynamic range for single channel: 5 MeV - 80 GeV
- 32 APD bias regulators
- Eight 2x2 analogue outputs for the Trigger Region Unit (TRU)
- FPGA board controller
- Four ALICE TPC Readout (ALTRO) ASICs

PHOS trigger: Trigger Region Unit (TRU) and Trigger OR (TOR)
- Each PHOS module has eight TRUs for a total of 40 TRUs for the full PHOS detector
- Each TRU receives a total of 112 2x2 analogue sums from 14 front-end cards
- The TOR receives the 40 inputs from the TRU and makes a L0 and a L1 trigger decision
  - L0: Simple OR of the TRU inputs
  - L1: Low, medium and high $P_T$ together with L1 trigger message
Light mesons measured at SPS in 2003 with 256ch prototype

π^0 meson
\[ M_{\pi^0} = 135.9 \pm 0.2 \text{ MeV} \]
\[ \sigma = 8.39 \pm 0.21 \text{ MeV} \]

\( N \) counts

η meson
\[ M_{\eta} = 544 \pm 2 \text{ MeV} \]
\[ \sigma = 17.6 \pm 2.5 \text{ MeV} \]

Energy resolution for all beam tests

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Results from ALICE at P2

Noise: Light blue = one ADC count (5 MeV)

Cosmics

Warm PHOS prediction: ΔE/E=0.28 at MIP peak

High Level Trigger

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The PHoton Spectrometer (PHOS) of the ALICE experiment
One PHOS module commissioned and installed in ALICE

Noise levels acceptable, dead channels $\sim 1\%$, mainly due to a single front-end card missing (32 out of 3584)

High Level Trigger
- On-line event reconstruction successfully tested up to $\sim 2$ KHz
- On-line event display and data quality monitoring
- Data compression by a factor $\sim 15$

PHOS Operated at room temperature due to condensation of water
- The light yield is 3 times less than at -25 degrees
- OK for physics, but not optimal
- MIP signal in the order of $\sim 10$ ADC counts $\rightarrow$ Calibration with cosmic rays becomes difficult (impossible)

The first PHOS module was ready and waiting for the first p+p collisions $\rightarrow$ incident in the LHC tunnel so collisions can be expected at earliest during spring 2009
Plants

- Flushing of warm PHOS volume with nitrogen
  - Requires new air tight design of module casings
- The module currently installed at P2 will be moved back to the PHOS lab for modification of casings
- Three modules with air tight design, operated at -25 degrees, to be installed by the restart of LHC in spring/summer 2009.
Backup Slides
The PHoton Spectrometer (PHOS) of the ALICE experiment
Infrastructure at ALICE

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The PHoton Spectrometer (PHOS) of the ALICE experiment
Trigger connectivity
The ALICE High Level Trigger (HLT)

1. L0 pre trigger from sub detectors
   - TRD Trigger
   - Global Trigger

2. L0
   - TRD
   - TPC
   - Di muon
   - ITS
   - PHOS

3. L1
   - Cluster finder & tracker
   - Cluster finder & tracker
   - Cluster finder & tracker
   - Clusterfinder & deconvolution of showers

4. L2 accept
   - 18 DDL 8 MB/evt
   - 216 DDL 76 MB/evt
   - 10 DDL 500 kB/evt
   - 10 DDL 7 k MB/evt

5. HLT trigger decision
6. Accept?
7. Compression
8. Mass storage

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The PHoton Spectrometer (PHOS) of the ALICE experiment
The data rate after the L0, L1, L2 trigger decision amounts to more than 20 Gbyte/s. The bandwidth to storage is 1.25 Gbyte/s. By on-line analysis the available bandwidth can be set aside for the most interesting physics events.

**The HLT for PHOS**

- Extraction of Energy and Time of Flight from time dependent signal
- Clusterization
- Make Event Summary Data (ESD)
- Compress data by a factor 15 - 50