Thermal radiation and direct photon production in Pb–Pb and pp collisions with dielectrons in ALICE

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Introduction

**pp**
- Vacuum baseline for p—Pb and Pb—Pb
- Search for new phenomena in high-multiplicity events \( \Leftarrow \text{New} \)

**p—Pb**
- Cold nuclear matter (CNM) effect
  
  \[ \text{PRC 102 (2020) 055204} \]
- Search for new phenomena in central collisions

**Pb—Pb**
- Thermal Radiation from QGP and HG \( \Leftarrow \text{New} \)
- Chiral symmetry restoration via \( \rho \) modification
- Coherent photoproduction via \( \gamma \gamma \rightarrow e^- e^+ \)
  
  [Parallel talk, Laure Massacrier, 13-Jun]

**Thermal radiation can be addressed**
- \( m_{ee} \) and \( DCA_{ee} \) analysis at intermediate mass region
  
  (IMR: \( 1.1 < m_{ee} < 2.7 \text{ GeV}/c^2 \))
- Direct photon analysis via virtual-photon \( \gamma^* \) analysis \( (m_{ee} \rightarrow 0) \)
ALICE experiment

**Inner Tracking System**
- Vertexing
- Tracking
- Particle identification

**Time Projection Chamber**
- Tracking
- Particle identification

**Time-Of-Flight**
- Particle identification

**V0 scintillation counter**
- Trigger : minimum-bias (MB) & high-multiplicity (HM)
- Multiplicity determination
- Centrality estimation

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### Analyzed datasets in this talk

<table>
<thead>
<tr>
<th>Collision system</th>
<th>Analyzed luminosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pb–Pb at $\sqrt{s_{NN}} = 5.02$ TeV</td>
<td>84 $\mu$b$^{-1}$ (0-10%)</td>
</tr>
<tr>
<td>pp at $\sqrt{s} = 13$ TeV</td>
<td>30 nb$^{-1}$ (MB)</td>
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<tr>
<td></td>
<td>6 pb$^{-1}$ (HM, top 0.1%)</td>
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</tbody>
</table>

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SQM22, Busan, Korea

Thermal radiation and direct photon production in Pb–Pb and pp with dielectrons
Full Run 2 datasets analyzed
  - Factor 3.8 in MB compared to previous publication
  - $\pi^0$ and $\eta$ measured at $\sqrt{s} = 13$ TeV in MB

$\rightarrow$ Reduced the sys. unc. of the hadronic cocktail
  - Cocktail reproduces data $p_{T,ee} > 1$ GeV/c within uncertainty.
Full Run 2 datasets analyzed
- Factor 4.4 in HM compared to previous publication

- $\pi^0$ and $\eta$ measured at $\sqrt{s} = 13$ TeV in the same multiplicity class
  Parallel talk, Adrian Nassirpour 13 Jun

→ Reduced the syst. unc. of the hadronic cocktail

- HF cocktail: applied $p_T$ dependent multiplicity scaling factor

→ The scaling factor dominates the cocktail unc. at IMR

- Within uncertainty, no excess w. r. t. data

**pp at $\sqrt{s} = 13$ TeV in high-multiplicity events - Invariant mass spectrum**
Extraction of direct photon fraction $r$

- Relation is given by Kroll-Wada formula
  \[ \frac{d^2N_{ee}}{dm_{ee}} = \frac{2\alpha}{3\pi m_{ee}} \sqrt{1 - \frac{4m_{ee}^2}{m_{ee}^2}} \left( 1 + \frac{2m_{ee}^2}{m_{ee}^2} \right)^2 \left( 1 - \frac{m_{ee}^2}{M_h^2} \right)^3 \frac{dn_{\gamma}}{m_{ee}} \]

  N.M. Kroll and W. Wada PR 98 (1955) 1355

  Process dependent form factor
  \[ \rightarrow \text{Hadrons} : 0, \text{Virtual photons} : 1 \]

- Exploit the difference to separate virtual photon and dielectron from Dalitz decay

- Yield fitted with:
  \[ f = r \times f_{\text{dir}} + (1-r) \times f_{\text{LF}} + f_{\text{HF}} \]

  Virtual-photon template and
  Light flavor

  where \[ r = \left( \frac{\gamma_{\text{dir}}^*/\gamma_{\text{incl}}^*}{m_{ee}} \right) m_{ee} \rightarrow 0 = \left( \frac{\gamma_{\text{dir}}/\gamma_{\text{incl}}}{} \right) \]

  Heavy flavor

- Assumption only valid for $p_{T,ee} \gg m_{ee} \rightarrow$ Extract $r$ at $p_{T,ee} > 1 \text{ GeV}/c$

ALICE Preliminary
0–10% Pb–Pb at $\sqrt{s_{NN}} = 5.02 \text{ TeV}$
$0.2 < p_{T,e} < 10 \text{ GeV}/c, |\eta_e| < 0.8$
$1.2 < p_{T,ee} < 1.6 \text{ GeV}/c$

\[
\chi^2/\text{NDF} = 11.34/4
\]

\[ r = 0.039 \pm 0.020 \text{ (stat.)} \]
Direct photon fraction in pp collisions at $\sqrt{s} = 13$ TeV

- Much smaller statistical and systematic uncertainties compared with previous publication
- No significant increase with respect to pQCD photons in MB
- No sign of increase direct photon fraction in HM w. r. t. MB
Central Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV - Invariant mass spectrum

- Data compared with hadronic cocktail with $<N_{\text{coll}}>$ scaled heavy flavor (HF) measured in pp at $\sqrt{s} = 5.02$ TeV
  - Vacuum baseline
  - Cocktail underestimates data slightly at IMR
    - HF cocktail modified by CNM and hot medium effect
      - Vacuum baseline $\times R_{AA}(c/b \rightarrow e^\pm)$
  - Data is consistent with HF suppression & thermal radiation from QGP

\[ \text{Phys. Rev. C 102 (2020) 055204} \]

\[ \text{Phys. Lett. B 804 (2020) 135377} \]
Central Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV – Extraction of prompt thermal signal

- Difficulty in extraction of prompt thermal $e^+e^-$ from QGP at IMR due to huge non-prompt correlated HF background
- Separate prompt and non-prompt sources via impact parameter

\[ \text{DCA}_{ee} = \sqrt{\frac{\text{DCA}_1^2 + \text{DCA}_2^2}{2}} \]

- Expectations: prompt + non-prompt ($c\bar{c}$ and $b\bar{b}$)
  - $\text{DCA}_{ee} \text{(prompt)} < \text{DCA}_{ee} \text{ (c\bar{c})} < \text{DCA}_{ee} \text{ (b\bar{b})}$

Poster, Jerome Jung, 14 Jun

Thermal radiation and direct photon production in Pb–Pb and pp with dielectrons

ALICE Preliminary

- Data
- Cocktail sum
- $c\bar{c} \rightarrow e^+e^-$ (POWHEG+$N_{coll}$+R$_{AA}^{c\bar{c}\rightarrow e^+e^-}$)
- $b\bar{b} \rightarrow e^+e^-$ (POWHEG+$N_{coll}$+R$_{AA}^{b\bar{b}\rightarrow e^+e^-}$)
- $J/\psi \rightarrow e^+e^-$, $J/\psi \rightarrow \gamma e^+e^-$
- in-med. hadronic [Rapp]
- QGP radiation [Rapp]
- Upper limit at 90% C.L.
Central Pb–Pb collisions at √s_{NN} = 5.02 TeV – Extraction of prompt thermal signal

- Fix $b\bar{b}$ contribution via fit at high $DCA_{ee}$
  - $b\bar{b} = 0.74 \pm 0.24 \text{ (stat.)} \pm 0.12 \text{ (syst.)}$
    w.r.t. $N_{coll}$ scaling
- Simultaneous fit $c\bar{c}$ and prompt contributions
  - $c\bar{c} = 0.43 \pm 0.40 \text{ (stat.)} \pm 0.12 \text{ (syst.)}$
    w.r.t. $N_{coll}$ scaling
  - prompt $= 2.64 \pm 3.18 \text{ (stat.)} \pm 0.29 \text{ (syst.)}$
    w.r.t. R. Rapp
- Results agree with:
  - Charm suppression
  - Thermal contribution in the order of Rapp/PHSD

**Poster, Jerome Jung, 14 Jun**

![Graph showing the relationship between prompt and prompt contributions with Rapp.](attachment:image)

ALICE Preliminary
0-10% Pb–Pb $\sqrt{s_{NN}} = 5.02$ TeV
$1.1 < m_{ee} < 2.6 \text{ GeV} / c^2$

- DCA_{ee} fit ($\chi^2/ndf = 2.51/6$)
- Syst. unc. of data
- Stat. unc. of fit
- Theory comparison:
  - Thermal R. Rapp
  - Thermal PHSD

New
Central Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV - Direct photon excess ratio $R_\gamma$

- Direct photon excess ratio: $R_\gamma = \gamma_{\text{incl}}/\gamma_{\text{decay}}$
- Two methods: real photon analysis via gamma conversion (PCM) in the detector, virtual photon analysis (dielectron)
- Both analyses are in good agreement.
Central Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV - Direct photon spectrum

- Direct photon excess ratio: $R_\gamma = \gamma_{incl}/\gamma_{decay}$
- Two methods: real photon analysis via gamma conversion (PCM) in the detector, virtual photon analysis (dielectron)
- Both analyses are in good agreement.
- Direct photon yield constructed as $\gamma_{dir} = \gamma_{incl} \times r$

Inclusive photon spectrum from PCM

New
Central Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV - Direct photon spectrum

- Direct photon yield compared to theoretical models
  
  **Thermodynamic models**: C.Gale/H.vanHees/P.Dasgupta

  **Microscopic transport model (PHSD)**: O. Linnyk

- All models agree with the data but some tends to overestimate them at low $p_T$

![Graph showing direct photon spectrum](ALICE Preliminary 0–10% Pb–Pb at $\sqrt{s_{NN}} = 5.02$ TeV)

Data
- C.Gale et al., PRC 105, 014909
- H.van Hees et al., NPA 933, 256
- O.Linnyk et al., PRC 92, 054914
- P.Dasgupta et al., PRC 98, 024911

New

Thermal radiation and direct photon production in Pb–Pb and pp with dielectrons
Future prospects

Run 3 and Run 4

- New ITS
  - Improved vertex resolution
  - Separate HF from prompt $e^+e^-$ sources
- TPC upgrade
  - GEM-based readout
  - Continuous readout in Pb–Pb $\sim$ 50 kHz
- Pb–Pb
  - Increase factor $100 \sim 13 \text{ nb}^{-1}$ from entire Run 3 + Run 4
- pp
  - Future High-energy pp program (2022 - )
    ALICE-PUBLIC-2020-005 CERN-LHCC-2020-018; LHCC-G-179
  - Min. bias pp $\sim$ 200 pb$^{-1}$
  - High mult pp $\sim$ 3 pb$^{-1}$
Summary

- **pp at $\sqrt{s} = 13$ TeV in MB and HM events**
  - Within uncertainty no excess w.r.t. cocktail at IMR in HM
  - No significant increase with respect to pQCD photons in MB
  - No sign of increase direct photon fraction in HM w.r.t MB

- **Pb–Pb at $\sqrt{s_{NN}} = 5.02$ TeV in central collision**
  - First $DCA_{ee}$ analysis to separate thermal radiation & HF background
  - First measurement of direct photon spectrum with virtual photon method

- **Run 3 & Run 4 and beyond**
  - With upgraded ITS and TPC, much more statistics will be expected
  - ALICE enters Quantitative/Precision era

Plenary talk, Sarah Porteboeuf, 16.Jun
Plenary talk, Raphaëlle Bailhache, 16.Jun