Elisa Meninno on behalf of the ALICE Collaboration
Stefan Meyer Institute for Subatomic Physics, Vienna

Low-mass dielectron measurements with ALICE at the LHC
• Physics motivation
• The ALICE experiment
• Low-mass dielectron analyses in ALICE
  • Studies in pp, p–Pb and Pb–Pb collisions
• Outlook

Focus on recent results with LHC Run 2 data in pp and p–Pb collisions @ $\sqrt{s} = 5$ TeV
Electromagnetic probes

- Dileptons and photons experience no strong interactions, can therefore directly probe full phase extension of the collisions
  - Penetrating probes, information from earliest stages well preserved

- Dileptons emitted from many sources during all stages of the collisions
  - Investigate the whole history of the medium

- Measurements in small systems (pp and p–Pb collisions)
  - Crucial reference for Pb-Pb studies
  - Investigate possible cold nuclear matter effects
Different sources:

- Dalitz decays ($\pi^0, \eta, \omega, \eta', \phi$) and 2-body decays ($\rho, \omega, \phi$) of light-flavour mesons

- $\rho$: Sensitive to chiral symmetry restoration in the hot hadronic phase

$m_{ee} < 1.1 \text{ GeV}/c^2$
Dielectron mass spectrum

Different sources:

• Dielectrons from decays of correlated heavy-flavour hadrons
  
  decay semileptonically $\bar{c}c \rightarrow D \bar{D} \rightarrow XY e^+e^-$

• $\sigma_{c\bar{c}}$ and $\sigma_{b\bar{b}}$ measurements

• Nuclear Parton Distribution Functions (nPDFs) in p–Pb and Pb–Pb collisions

• Energy loss, partial thermalization of correlated charm and beauty quarks

$1.1 < m_{ee} < 2.7 \text{ GeV/c}^2$

[ALICE Simulation graph showing yield vs. $m_{ee}$]
Dilepton mass spectrum

Different sources:

Thermal radiation

- Quark-gluon plasma

- Hadronic gas

In the intermediate mass region (IMR)

- Thermal radiation from the partonic phase

\[
\frac{dN_{ee}}{dm_{ee}} \sim m_{ee}^{3/2} e^{-m_{ee}/T}
\]

- Challenging due to the dominant contribution from charm and beauty hadrons
The ALICE apparatus

1. ITS
2. FMD, T0, V0
3. TPC
4. TRD
5. TOF
6. HMPID
7. EMCal
8. DCal
9. PHOS, CPV
10. L3 Magnet
11. Absorber
12. Muon Tracker
13. Muon Wall
14. Muon Trigger
15. Dipole Magnet
16. PMD
17. AD
18. ZDC
19. ACORDE

a. ITS SPD (Pixel)
b. ITS SDD (Drift)
c. ITS SSD (Strip)
d. V0 and T0
e. FMD

IS 2021

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The ALICE apparatus

**Inner Tracking System (ITS)**
- Vertexing, tracking, PID
- $|\eta| < 0.9$

**Time Projection Chamber (TPC)**
- Tracking, PID via $dE/dx$ measurement
- $|\eta| < 0.9$

**Time-Of-Flight detector (TOF):**
- PID via time-of-flight measurement
- $|\eta| < 0.9$

**V0**
- Trigger and centrality determination
- $-3.8 < \eta < -1.7$ (V0C)
- $2.8 < \eta < 5.1$ (V0A)
Obtaining the dielectron spectrum

• Track quality cuts applied to ensure only “good” quality tracks are used

• Particle identification performed
  • TPC, TOF used

• Photon conversion into dielectrons needs to be removed

• Subtract combinatorial background via like-sign subtraction:

\[ LS_{all} = R \cdot \sqrt{N_{++} \cdot N_{--}} \]

\[ US_{signal} = US_{all} - LS_{all} \]

• S/B \sim 10^{-2} in pp and p–Pb collisions

Additional factor to account for different acceptances between ++ and – pairs
Dielectron measurements in pp collisions

• Spectrum compared with cocktail of known hadronic sources
  • **Data well described by cocktail within uncertainties**
  • Similar results in pp collisions at $\sqrt{s} = 7$ TeV and 13 TeV

• Light flavour and $J/\psi$ from parametrized measurements and particle ratios
• Heavy flavour from POWHEG or PYTHIA, $m_{ee}$ and $p_{T,ee}$ shapes normalized to our own measurements of $\sigma_{c\bar{c}}$ and $\sigma_{b\bar{b}}$

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Dielectron measurements in pp collisions

- HF cross sections extracted with a 2D $m_{ee} p_{T,ee}$ fit (pp@5,7,13 TeV)
Dielectron measurements in pp collisions

- MC (PYTHIA and POWHEG) generator dependence observed in all available energies
- Charm and beauty cross sections compatible with previous measurements of HF hadron decays

Dielectron measurements in p-Pb collisions

- Spectrum in good agreement with cocktail of known hadronic sources
  - Heavy flavour from PYTHIA or POWHEG based on binary NN collision scaled measured $\sigma_{c\bar{c}}$ and $\sigma_{b\bar{b}}$ in pp collisions at 5.02 TeV

- No significant deviation from vacuum expectation
  - Cold nuclear matter effects seem small compared to current measurement uncertainties.

\begin{align*}
\sqrt{s_{NN}} &= 5.02 \text{ TeV}, \ |\eta_e| < 0.8 \\
0.2 < p_{T,e} < 10 \text{ GeV/c} \\
p_{T,ee} < 8 \text{ GeV/c} \\
\pm 3.7\% \text{ norm. uncertainty}
\end{align*}


$p\text{-Pb@}\sqrt{s_{NN}} = 5 \text{ TeV}$
\[ R_{pPb} = \frac{1}{A} \frac{d\sigma_{ee}^{pPb}}{d\sigma_{ee}^{pp}} / d m_{ee} \]

- Comparison to models including only scaling effects or nuclear shadowing (EPS09):
  - Data compatible with both models within uncertainties
  - EPS09 seem disfavored in IMR
- Thermal radiation can not be excluded by the data.
  - Important to separate dielectrons from HF and from thermal radiation

Thermal radiation model by R. Rapp:
\[ R_{pPb} = \frac{1}{A} \frac{d\sigma^{pPb}_{ee} / dm_{ee}}{d\sigma^{pp}_{ee} / dm_{ee}} \]

- Above 1 GeV/c LF sources scale with binary NN collisions
- Deviation from unity for \( p_{T,ee} < 1 \text{ GeV/c} \)
  - Can be described by hadronic cocktail
- Compatible with unity in the IMR
  - EPS09 parametrization disfavored by data
Measurements in Pb–Pb

- HF: PYTHIA6 binary NN collision scaling
- Deviation from cocktail for $m_{ee}$ in $0.5 - 2.5$ GeV/$c^2$
- Suppression observed in HF region
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- Hint for enhancement at low $m_{ee}$?
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- Discrepancy reduced when nPDF included
- Hint for enhancement at low $m_{ee}$?
  - Compatible with thermal radiation models
First studies in 2018 Pb-Pb collisions

- Ongoing studies look very promising!
- Higher statistics (9 times more data in 0-10% centrality) reduce statistical fluctuations, mainly in the low-mass region
Future dielectron measurements

Upgrade of ITS and TPC:

- improved vertex resolution, reduced material budget, 50 times higher acquisition rate
- Better separation of prompt sources (thermal radiation) from HF electrons, via DCA studies
- Sensitivity to in-medium modified $\rho$ spectral function
Summary

Dielectron measurements in pp, p–Pb and Pb–Pb collisions

pp
• Measurement of charm and beauty cross sections
• Model dependence of heavy-flavour production

p–Pb
• No significant modification of heavy-flavour production in IMR, hint of $R_{pPb} < 1$ for smaller masses
• Important to separate thermal radiation and HF in the IMR

Pb–Pb
• Possible excess from thermal radiation $\sim 0.5$ GeV/$c^2$?
• Suppression of heavy flavour from final state effects
• Very promising first studies in 2018 Pb-Pb collisions
Backup
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**Used data samples:**

**pp collisions:**
- Run 1 $\sqrt{s} = 7$ TeV (2009 - 2013),
- Run 2 $\sqrt{s} = 5.02$ TeV (2015, 2017) and $\sqrt{s} = 13$ TeV (2015 - 2018)

**p–Pb collisions:**
- Run 2 $\sqrt{s_{NN}} = 5.02$ TeV (2016)

**Pb–Pb collisions**
- Run 1 $\sqrt{s_{NN}} = 2.76$ TeV (2010, 2011)
- Run 2 $\sqrt{s_{NN}} = 5.02$ TeV (2015, 2018)
• Excess with respect to hadronic and thermal sources in peripheral collisions
  • Compatible with calculations for dielectron production from coherent photon-photon interactions

STAR, Phys. Rev. Lett. 121. 132301
Low $p_T$ analysis in Pb–Pb

**Photo-Production in Pb–Pb**

- Analysis performed in the mass range dominated by HF, $1.1 < m_{ee} < 2.7$ GeV/$c^2$

- No significant discrepancy observed in 0-40% centrality

$\text{Pb-Pb@}\sqrt{s_{NN}} = 5 \text{ TeV}$
Low $p_T$ analysis in Pb–Pb

**Photo-Production in Pb–Pb**

- Analysis performed in the mass range dominated by HF, $1.1 < m_{ee} < 2.7$ GeV/c$^2$
- Centrality class 70-90% more sensitive to the photo-production than 0-40%
  - Excess w.r.t. cocktail and thermal sources at $p_{T,ee} < 0.1$ GeV/c
  - Compatible with photo-production models
  - Excess observed at the same $p_{T,ee}$ range as at STAR

**Outlook:**

2018 data: **2 times more statistics** in 70-90% centrality!

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STAR, Phys. Rev. Lett. 121. 132301
Soft dielectrons in pp 13 TeV


- Low-mass region (LMR) excess:
- Not explainable with contribution of known hadronic decays

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Distinct shape of charm and beauty in $m_{ee}$, $p_{T,ee}$, and $DCA_{ee}$ can be used to fit cross sections.

Model dependence observed, similar to what observed in pp collisions at $\sqrt{s} = 7$ TeV and 13 TeV.

<table>
<thead>
<tr>
<th></th>
<th>$d\sigma_{cc}/dy$</th>
<th>$d\sigma_{bb}/dy$</th>
</tr>
</thead>
<tbody>
<tr>
<td>PYTHIA</td>
<td>$0.531 \pm 0.062$ (stat.) $\pm 0.066$ (syst.) mb</td>
<td>$0.037 \pm 0.004$ (stat.) $\pm 0.005$ (syst.) mb</td>
</tr>
<tr>
<td>POWHEG</td>
<td>$0.743 \pm 0.080$ (stat.) $\pm 0.093$ (syst.) mb</td>
<td>$0.027 \pm 0.004$ (stat.) $\pm 0.003$ (syst.) mb</td>
</tr>
</tbody>
</table>
pp reference measurements @ $\sqrt{s} = 7$ TeV and 13 TeV

- Spectrum compared with cocktail of known hadronic sources
  - Data described by cocktail within uncertainties
- Dielectron production well understood for $p_{T,e} > 0.2$ GeV/c
- Heavy-flavour contributions dominate for $m_{ee} > 1.1$ GeV/c^2
- Complementary (w.r.t. heavy-flavour hadron measurements) $\sigma_{c\bar{c}}$ and $\sigma_{b\bar{b}}$ measurements
Dielectron measurements in pp collisions

- DCA dielectron spectra in IMR used to extract charm and beauty cross section

\[ pp@\sqrt{s} = 7 \text{ TeV} \]

- Heavy-flavour hadrons have a delayed decay
- D-meson \( c\tau = 150-300 \, \mu m \), B-meson \( c\tau = 450 \, \mu m \)

\[ DCA_{ee}^\text{prompt} < DCA_{ee}^\text{charm} < DCA_{ee}^\text{beauty} \]

\[ DCA_{ee} = \sqrt{\frac{DCA_1^2 + DCA_2^2}{2}} \]

DCA useful variable to discriminate charm and beauty hadron decay electrons

- Additional fit with DCA (in pp collisions at \( \sqrt{s} = 7 \text{ TeV} \)
$R_{pPb}$ vs $p_T$ (GeV/c)

**ALICE**

**p-Pb, $\sqrt{s_{NN}}=5.02$ TeV**

Prompt D mesons, $-0.96 < y_{cms} < 0.04$

- Average $D^0$, $D^+$, $D^{++}$
- $D^0$

**Models**

- CGC (Fujii-Watanabe)
- pQCD NLO (MNR) with CTEQ6M+EPS09 PDF
- Vitev et al.: power corr. + $k_T$ broad + CNM Eloss
- Kang et al.: incoherent multiple scattering

**EPPS16/EPS09 for nPDF**