Azimuthal angular correlations of D mesons and charged particles in pp at 7 TeV and p-Pb at 5.02 TeV with the ALICE detector at the LHC

Fatiha Lehas

for the ALICE collaboration
5th International Conference on New Frontiers in Physics 2016
1 Motivation

2 ALICE detector

3 Analysis strategy

4 Results

5 Conclusions and Outlook
Outline

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5 Conclusions and Outlook
Why heavy flavours?

in pp collisions
- Test for pQCD calculations for the production cross-sections.
- Reference for p-Pb and Pb-Pb measurements.

in p-Pb collisions
- Control experiment for the Pb-Pb measurements.
- Studies of cold nuclear matter effects.

in Pb-Pb
- Studies on the interaction of heavy quarks with the medium.
- Study the transport properties in the hot and dense medium.
Why D-hadron correlations studies are interesting?

Why Correlations?

- Flavour conservation in QCD (charm quarks are produced in pairs) $\Rightarrow$ Jet formation due to the fragmentation of charm quark.
- Correlation distributions are sensitive to the fragmentation and production mechanisms of charm quarks in pp collisions.
- Angular correlations are investigated also in p-Pb collisions for possible modifications due to the presence of cold nuclear matter.

Why D-hadron correlations studies are interesting?

Why D mesons?

- \( D^0 = c\bar{u}, \quad D^+ = c\bar{d}, \quad D^{*+} = c\bar{d} \) (\( m_c \approx 1.5 \text{ GeV}/c^2 \)).
- \( Q^2 > 4m_c^2 \Rightarrow \alpha_s < 1 \Rightarrow \) pQCD calculation applicable
- \( D^0, D^+ \) and \( D^{*+} \) cross-section at \( \sqrt{s} = 7 \text{ TeV}, \ |y| < 0.5 \).
Outline

1. Motivation
2. ALICE detector
3. Analysis strategy
4. Results
5. Conclusions and Outlook
Central barrel
Pseudorapidity $|\eta| < 0.9$

Muon spectrometer
Pseudorapidity $-4.0 < \eta < -2.5$
**ALICE detector**

**Central barrel**

**ITS**
Inner Tracking System
vertexing, tracking and Particle Identification.

**TPC**
Time Projection Chamber
Tracking and Particle Identification.

**TOF**
Time-Of-Flight
Tracking and Particle Identification.

**pp@7TeV** 300 M minimum bias events
Integrated luminosity 5 $nb^{-1}$

**p-Pb@5.02TeV** 100 M minimum bias events
Integrated luminosity 50 $nb^{-1}$
ALICE detector: PID using ITS, TPC and TOF

PID ITS

PID TPC

PID TOF

More about PID in

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Analysis strategy : Steps

- **D meson (trigger) reconstruction - invariant mass spectra.**

- Associated tracks selection.

- Single-event (SE) and mixed-event (ME) distributions.

- Corrected single events for signal and background.

- Projection on $\Delta \varphi$ for signal and background.

- Normalise the $\Delta \varphi$-distributions to the number of triggers (D mesons).

- Remove secondary tracks.

- Remove the B feed-down contribution.
Analysis strategy - D-meson reconstruction

Topological cuts about 14 parameters:
- $p_T (K, \pi) \, [GeV/c]$
- $\min d_0 (K, \pi) \, [cm]$
- $\min d_0 \times d_0 \, [cm^2]$
- $\cos(\theta_{\text{Point}})$, ...

- Optimised to maximize the significance $(\frac{S}{\sqrt{S+B}})$ / Reduce the background / Keep the selection efficiency large enough.
- Selection cuts complemented by the particle identification (PID).
Analysis strategy: D-meson reconstruction

Selection criteria required for D-meson candidate daughters:

- $|\eta| < 0.8$, $\chi^2/NDF < 2$,
- $p_T > 0.3$ GeV/$c$ ($p_T > 0.1$ GeV/$c$ for $D^{*+}$),
- 70 (at least) out of 159 space points in the TPC,
- 2 (at least) out of 6 hits in the ITS.

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\[
D^0 \rightarrow K^- \pi^+ \\
\text{BR} \approx (3.88 \pm 0.05)\%
\]

\[
D^+ \rightarrow K^- \pi^+ \pi^+ \\
\text{BR} \approx (9.13 \pm 0.19)\%
\]

\[
D^{*+} \rightarrow D^0 \pi^+ \\
\text{BR} \approx (67.7 \pm 0.5)\%
\]
Invariant mass spectra

$D^* \Delta \text{InvMass in the range [5,8] GeV/c}$

- Peak $\Rightarrow$ Signal region $[\text{mean}-2\sigma, \text{mean}+2\sigma]$
- SB $\Rightarrow$ Sideband region $[\text{mean}+4\sigma, \text{mean}+8\sigma]$
- $M \Rightarrow$ Invariant mass spectra
- $Scale_{factor} = \frac{\int_{\text{Peak}} \text{Background}(M)}{\int_{\text{SB}} \text{Background}(M)}$

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- Fatiha Lehas (UU)
- Azimuthal angular correlations of D mesons a

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Analysis strategy: Single events (SE) and mixed events (ME)

\[ \Delta \varphi = \varphi^{assoc} - \varphi^{trigg}, \Delta \eta = \eta^{assoc} - \eta^{trigg} \]

\[ \frac{dN_{corr}(\Delta \varphi, \Delta \eta)}{d\Delta \varphi d\Delta \eta} = \frac{dN^{SE}(\Delta \varphi, \Delta \eta)}{d\Delta \varphi d\Delta \eta} \bigg/ \frac{dN^{ME}(\Delta \varphi, \Delta \eta)}{d\Delta \varphi d\Delta \eta} \bigg/ \frac{dN^{ME}(0,0)}{d\Delta \varphi d\Delta \eta} \]

\[ C_{\text{inclusive}}(\Delta \varphi) = \text{Signal}(\Delta \varphi) - \text{Scale}_{\text{factor}} \times \text{Background}(\Delta \varphi) \]
**Efficiency correction for D mesons**
A Monte Carlo (MC) sample is used (enhanced production). The efficiency map is obtained. Invariant mass spectra, SE and ME are weighted by the inverse of the efficiency.

**Efficiency correction for associated tracks**
A Monte Carlo (MC) Sample is used (minimum bias production). The efficiency map is obtained. SE and ME are weighted by the inverse of the efficiency.
Analysis strategy: B feed-down subtraction

Subtraction of the contribution of D meson from B using a MC PYTHIA template. Prompt D fraction \( f_{\text{prompt}} \) is computed using FONLL.

\[ f_{\text{prompt}} = \left( 1 + \frac{(\text{Acc} \times \epsilon)_{\text{feeddown}D^*+}}{(\text{Acc} \times \epsilon)_{\text{prompt}D^*+}} \frac{d\sigma}{dp_T} \right)_{\text{feed-down}} |y|<0.5 \]

\[ \tilde{C}_{\text{prompt}D}(\Delta \varphi) = \frac{1}{f_{\text{prompt}}} \left( \tilde{C}_{\text{inclusive}}(\Delta \varphi) - (1 - f_{\text{prompt}}) \tilde{C}_{\text{MCtempl} \text{feed-down}}(\Delta \varphi) \right) \]

Analysis strategy: Correction for the purity


\[
\text{Purity} = \frac{\int_0^{DCA_{cut}^{XY}} f_{\text{prim}}(DCA_{XY}) dDCA_{XY}}{\int_0^{DCA_{cut}^{XY}} f_{\text{prim}}(DCA_{XY}) + f_{\text{sec}}(DCA_{XY}) dDCA_{XY}}
\]

\[
C_{\text{promptD}}(\Delta \varphi) = \text{purity} \times \tilde{C}_{\text{promptD}}(\Delta \varphi)
\]
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Correlations in pp and p-Pb - baseline subtracted

\[ 5 < p_T < 8 \text{ GeV/c} \] \quad \text{and} \quad \[ 8 < p_T < 16 \text{ GeV/c} \]

The results from pp and p-Pb are compatible within uncertainties.

No significant cold nuclear matter effect affecting the distribution.

arXiv:1605.06963v1

- The results from pp and p-Pb are compatible within uncertainties.
- No significant cold nuclear matter effect affecting the distribution.
No significant difference between different event generators.

Measurements and Monte Carlo simulations are in agreement within uncertainties.
Measurements vs MC simulations

- The measured associated yield and the width of near-side peak are in agreement with the predicted ones from simulations within uncertainties.
- The measured baseline is well reproduced by the simulations.
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Conclusions and outlook

- D mesons - charged particles correlations were measured in pp collisions at 7 TeV and p-Pb collisions at 5.02 TeV.

- Correlation distributions in pp and p-Pb are similar i.e. there is no significant cold nuclear matter effects.

- The obtained results were compared with those obtained using different Monte Carlo generators which are in agreement with each other within uncertainties.

- Improved results are expected with the high statistics in Run2 and with the upgrade of the LHC Run3 and the upgraded ALICE ITS.
Thank you for your attention

Questions?
Comments!
Backup slides
Analysis strategy: Associated tracks reconstruction

Selection criteria for the associated track:

- ITS Refit: Yes
- TPC Refit: Yes
- Min number of ITS clusters: 3
- Min number of TPC clusters: 70
- $p_t\text{ min} : 0.3 \text{ [GeV/c]}$
- $p_t\text{ max} : 100 \text{ [GeV/c]}$
- $|\eta| < 0.8$
Correlations: $D$ meson average in $pp$ and $p$-$Pb$ for different $p_T$ ranges

- $pp$, $\sqrt{s} = 7$ TeV, $|\eta| < 0.5$
- $p$-$Pb$, $\sqrt{s_{NN}} = 5.02$ TeV, $-0.96 < y^D < 0.04$

Average $D^0$, $D^+$, $D_s^+$ ALICE

- $3 < p_T^D < 5$ GeV/$c$
- $0.3 < p_T^{assoc} < 1$ GeV/$c$
- Scale uncertainty (pp): +13% -10%
- Scale uncertainty (p-$Pb$): +10% -10%

- $5 < p_T^D < 8$ GeV/$c$
- $0.3 < p_T^{assoc} < 1$ GeV/$c$
- Scale uncertainty (pp): +14% -11%
- Scale uncertainty (p-$Pb$): +10% -10%

- $8 < p_T^D < 16$ GeV/$c$
- $p_T^{assoc} > 0.3$ GeV/$c$
- Scale uncertainty (pp): +13% -10%
- Scale uncertainty (p-$Pb$): +10% -10%
Correlations : Systematic uncertainties

<table>
<thead>
<tr>
<th>System</th>
<th>pp</th>
<th>p–Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-meson species</td>
<td>D⁰,D⁺⁺⁺,D⁺</td>
<td>D⁰,D⁺⁺⁺ (D⁺)</td>
</tr>
<tr>
<td>Signal, background normalization</td>
<td>±10%</td>
<td>±10%</td>
</tr>
<tr>
<td>Background Δφ distribution</td>
<td>±5%</td>
<td>±5% (±10%)</td>
</tr>
<tr>
<td>Associated-track reconstruction efficiency</td>
<td>+10%,−5%</td>
<td>±4%</td>
</tr>
<tr>
<td>Primary-particle purity</td>
<td>±5%</td>
<td>±3.5%</td>
</tr>
<tr>
<td>D-meson efficiency</td>
<td>±5%</td>
<td>±5% (±10%)</td>
</tr>
<tr>
<td>Feed-down subtraction</td>
<td>up to 8%, Δφ dependent</td>
<td>up to 8%, Δφ dependent</td>
</tr>
<tr>
<td>MC closure test</td>
<td>−2% (near side)</td>
<td>−2% (near side), ±2%</td>
</tr>
</tbody>
</table>
3 D mesons correlations in pp@7TeV and p-Pb@5.02TeV

Average $D^0$, $D^+$, $D^{++}$
- $\pm s = 7$ TeV
- $|y^D_{\text{cms}}| < 0.5$, $|\Delta \eta| < 1$
- $5 < p_T^D < 8$ GeV/c, $p_T^{\text{assoc}} > 1$ GeV/c

- Total fit
- Near side
- Away side
- Baseline

Scale uncertainty: $+13\%$, $-10\%$

Average $D^0$, $D^+$, $D^{++}$
- $\sqrt{s_{\text{NN}}} = 5.02$ TeV
- $-0.96 < y^D_{\text{cms}} < 0.04$, $|\Delta \eta| < 1$
- $8 < p_T^D < 16$ GeV/c, $p_T^{\text{assoc}} > 1$ GeV/c

- Total fit
- Near side
- Away side
- Baseline

Scale uncertainty: $+10\%$, $-10\%$
Correlations: D mesons average-hadron in pp and p-Pb

Azimuthal angular correlations of D mesons and charged particles in pp at 7 TeV and p-Pb at 5.02 TeV with the ALICE detector at the LHC.
Associated yield, NS sigma : pp vs p-Pb

$\sigma_{n,NS} > 0.3 \text{ GeV/c, } |\Delta\eta| < 1$  
$0.3 < \langle p^\text{assoc} \rangle < 1 \text{ GeV/c, } |\Delta\eta| < 1$  
$p^\text{assoc} > 1 \text{ GeV/c, } |\Delta\eta| < 1$

- $\langle p_T \rangle = 7 \text{ TeV, } |y^D_{\text{cms}}| < 0.5$
- $p-\text{Pb}, \sqrt{s_{NN}} = 5.02 \text{ TeV, }$
  
- $-0.96 < y^D_{\text{cms}} < 0.04$

<7% variation expected from different energy and rapidity (Pythia, Perugia 2011)
Associated yield and NS peak width for D mesons in p-Pb

\[ p_{T}^{\text{assoc}} > 0.3 \text{ GeV/c, } |\Delta \eta| < 1 \]

ALICE

\[ p_{T}^{\text{assoc}} > 1 \text{ GeV/c, } |\Delta \eta| < 1 \]

\[ 0.3 < p_{T}^{\text{assoc}} < 1 \text{ GeV/c, } |\Delta \eta| < 1 \]

- pp, \( s = 7 \text{ TeV, } |y_{\text{CMS}}^{D}| < 0.5 \)
- p-Pb, \( s_{\text{NN}} = 5.02 \text{ TeV, } -0.96 < y_{\text{CMS}}^{D} < 0.04 \)
- <7% variation expected from different energy and rapidity (Pythia, Perugia 2011)

POWHEG+PYTHIA6 pp simulation
\( s = 5.02 \text{ TeV, with EPS09 nPDF} \)
Efficiency x Acceptance map for $D^0 f(p_T, y_{lab})$

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

$D^0 \rightarrow K^- \pi^+$ and charge conjugate

Acceptance $\times$ efficiency

$\rho_T$ (GeV/c)

$y_{lab}$

Prompt $D^0$

Prompt $D^0$, No PID

Feed-down $D^0$

$2<p_T<5$ GeV/c

$5<p_T<8$ GeV/c

$8<p_T<16$ GeV/c

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Prompt $D^0$ cross-section - ratios between data and theoretical predictions

ALICE, pp, $\sqrt{s}=7$ TeV
Prompt $D^0$, $|y|<0.5$

Data
FONLL
GM-VFNS
LO $k_T$-fact

$\pm 3.5\%$ lumi, $\pm 1.3\%$ BR uncertainty not shown

$p_T$ (GeV/c)
Prompt $D^0$ cross-section

Prompt $D^0$, $|y|<0.5$

- ALICE
- FONLL
- GM-VFNS
- LO $k_T$ fact

$\frac{d^2\sigma}{dp_T dy}$ (mb GeV$^{-1}$c$^{-1}$)

$P_T$ (GeV/c)

$|y|<0.5$, $\pm 3.5\%$ lumi, $\pm 1.3\%$ BR uncertainty not shown

pp, $\sqrt{s}=7$ TeV
PYTHA vs p-Pb @ 5.02 TeV Data

[ 5 - 8 ] GeV/c

D meson - charged particle correlation
Average $D^0, D^+, D^-$
$5 < p_T^D < 8$ GeV/c, $p_T^{assoc} > 0.5$ GeV/c, $|\Delta\eta| < 1.0$

- p-Pb $\sqrt{s_{NN}} = 5.02$ TeV Data
- Simulations, pp $\sqrt{s} = 5.02$ TeV
- Pythia8
- Pythia6, Perugia2010
- Pythia6, Perugia2011

ALICE Preliminary

[ 8 - 16 ] GeV/c

D meson - charged particle correlation
Average $D^0, D^+, D^-$
$8 < p_T^D < 16$ GeV/c, $p_T^{assoc} > 1.0$ GeV/c, $|\Delta\eta| < 1.0$

- p-Pb $\sqrt{s_{NN}} = 5.02$ TeV Data
- Simulations, pp $\sqrt{s} = 5.02$ TeV
- Pythia8
- Pythia6, Perugia2010
- Pythia6, Perugia2011

ALICE Preliminary

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Azimuthal angular correlations of D mesons at 

08/07/2016
Equations used for the fit of the invariant mass spectra

- For $D^{*+}$
  \[
  \text{Signal}(\Delta M) = Y_D \frac{1}{\sqrt{2\pi}\sigma} e^{\frac{(\Delta M - \mu)^2}{2\sigma^2}}
  \]
  \[
  \text{Background}(\Delta M) = a \sqrt{\Delta M - m_\pi} \times e^{b(\Delta M - m_\pi)}
  \]

- For $D^0$ and $D^+$
  \[
  \text{Signal}(M) = Y_D \frac{1}{\sqrt{2\pi}\sigma} e^{\frac{(M - \mu)^2}{2\sigma^2}}
  \]
  \[
  \text{Background}(M) = a \times e^{b(M - m_\pi)}
  \]