MEASUREMENTS OF HEAVY-FLAVOUR DECAY ELECTRONS IN PB-PB COLLISIONS WITH ALICE AT LHC

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2015 US LHC USERS ASSOCIATION MEETING
11-13 NOVEMBER 2015
INTRODUCTION

Discovery of asymptotic freedom lead to the prediction of a deconfined state of quarks and gluons at high temperature and pressure → Quark Gluon Plasma.

A unique way to study QCD matter in lab is by colliding heavy-ions at relativistic energies.

- Reaching energy density above $1 \text{ GeV/fm}^3$

Currently at LHC, Pb ions collide at $\sqrt{s_{\text{NN}}} = 2.76$ TeV.

- Run 2 : $\sqrt{s_{\text{NN}}} = 5.02$ TeV.
WHY STUDY HEAVY FLAVOUR?

Charm and beauty quarks (heavy quarks)

- Mainly produced in hard scattering processes in the initial stage of the collisions with high $Q^2$ values.
- Traverse the medium undergoing elastic and inelastic collisions in the QGP.
- Sensitive to the transport properties of the medium.

Heavy quarks lose less energy compared to light quarks and gluons in the QCD medium

- Color coupling factor $\Rightarrow \Delta E_g > \Delta E_q$
- Due to Dead cone effect\(^1\): suppression of gluon radiation at forward angles $\theta < M/E$.

Harder fragmentation $\Rightarrow$ measured hadron properties are closer to parton properties.

One way to study heavy-quark production is using its semi-leptonic decay channel.

- $c, b \rightarrow l \ (e, \mu) + X$.
- Large branching ratio (10%).
- Leptons can be used as trigger particles.
- High momentum electrons $\rightarrow$ clean signature in electromagnetic calorimeter.
- Present here heavy-flavour decay electron (HFE) measurements.
ALICE DETECTOR

Detectors used for analysis:

**Inner Tracking System**
-tracking, primary vertex reconstruction.

**Time Projection Chamber**
-tracking, momentum and dE/dx measurement.

**Time of Flight**
-PID.

**Transition Radiation Detector**
-Electron ID and trigger.

**Electromagnetic calorimeter**
-Energy measurement, EMC trigger.

**VZero**
-MinBias trigger, centrality and event plane estimation.

**Silicon Pixel Detector**
-MinBias trigger.

US Detector contribution: EMCal + DCal (from Run 2)
ELECTRON MEASUREMENT

Important background electron sources:
- Photon conversion, Dalitz decays of neutral mesons and quarkonium decays.

Background electrons subtracted using:
- Cocktail method
  - Background calculated based on measured pion $p_T$-differential yield ($\eta$ and $J/\Psi$ spectra used when available).
- Invariant mass method
  - Reconstruction of electron-positron pairs from decays of neutral mesons and photon conversions.

Electron identification
- TOF : $\pm 3 \sigma$ on electron hypothesis.
- TPC $dE/dx$ : 0-3 $\sigma$ of electron Bethe-Bloch band.
- EMCal : $0.8 < E/p < 1.2$
NUCLEAR MODIFICATION FACTOR ($R_{AA}$)

$$dN_{PbPb}/dP_t < \langle N_{coll} \rangle dN_{pp}/dp_t$$

$$R_{AA}(p_t) = \frac{1}{\langle N_{coll} \rangle} \frac{dN_{PbPb}/dp_t}{dN_{pp}/dp_t}$$

$\langle N_{coll} \rangle \rightarrow$ average number of binary nucleon-nucleon collision
d$N_{PbPb}/dp_T \rightarrow$ measured $p_T$ differential cross section in Pb-Pb collisions
d$\sigma_{pp}/dp_T \rightarrow$ reference $p_T$ differential cross section in pp collisions at the same $\sqrt{s}$ as Pb-Pb collisions.

$R_{AA} = 1 \rightarrow$ Absence of nuclear matter effects

$R_{AA} < 1 \rightarrow$ Indicates suppression of the observed yield in Pb-Pb collisions relative to pp collisions.
Heavy flavour decay electrons

$2.76 \text{ TeV Pb-Pb (0-10\%), } |\eta|<0.6$

$\text{1/2} \pi \frac{d^2 N}{d\eta d\phi}(\text{GeV/c})^2$

$\frac{dN}{dp_T}$ distribution for Pb-Pb collisions and pp references ($<T_{AA}>$ scaled)

- pp reference:
  - $p_T < 8 \text{ GeV/c} : 7 \text{ TeV data scaled with p-QCD FONLL scaling}$
  - $p_T > 8 \text{ GeV/c} : p$-QCD FONLL prediction
- Comparison with FONLL prediction for pp reference (M.Cacciari et al. JHEP 0103 (2001) 006)
HFE $R_{AA}$ IN 0-10% AND 40-50% CENTRAL Pb-Pb COLLISIONS

$R_{AA}(0-10\%)$ for $p_T^e < 18$ GeV/c

$R_{AA}(40-50\%)$ for $p_T^e < 10$ GeV/c

Clear suppression of heavy flavour decay electrons ($R_{AA} \sim 0.4$) w.r.t reference pp reference in (0-10%) central Pb-Pb events.

$R_{AA}$ of $\sim 0.6$ observed for semi-central Pb-Pb collisions.

$R_{AA}(0-10\%) < R_{AA}(40-50\%)$. 

\[ R_{AA} = \frac{1}{T_{AA}} \cdot \frac{dN_{PbPb}}{dp_T} / \frac{d\sigma_{pp}}{dp_T} \]
AZIMUTHAL ANISOTROPY ($v_2$) OF ELECTRONS

One observables sensitive to the dynamics of the early stages of Pb-Pb collision is the azimuthal distribution of the emitted particles in the plane perpendicular to the beam direction.

When nuclei collide at non-zero impact parameter the initial matter distribution is anisotropic (almond shaped).

- If matter is strongly interacting $\rightarrow$ spatial asymmetry converted into an anisotropic momentum distribution.

- Anisotropy characterized by Fourier co-efficient.

- Second moment called elliptic flow ($v_2$).

\[ v_2 = \langle \cos [2(\phi - \Psi_{RP})] \rangle \]

$\phi$ is the azimuthal angle of the particle

- Hydrodynamical models can describe the measurements of elliptic flow for light hadrons at low $p_T$ ($p_T < 2-3$ GeV/c).
AZIMUTHAL ANISOTROPY ($v_2$)

\[
\frac{dN}{d\varphi} = \frac{N_0}{2\pi} \left( 1 + 2v_1 \cos(\varphi - \Psi_1) + 2v_2 \cos(\varphi - \Psi_2) + \ldots \right)
\]

heavy-flavour decay electrons ($|y|<0.7$) compared with heavy-flavour decay muons ($2.5 < y < 4$)

Non-zero $v_2$ observed in semi-central Pb-Pb collisions.

Indication for $v_2(20-40%) > v_2(10-20%) > v_2(0-10%)$.

$v_2$ of heavy-flavour decay electrons consistent with that of HF-decay muons.

Confirms strong interaction of heavy quarks with the medium.

Supports that charm quarks participate in the collective expansion of the medium.
Simultaneous description of HF-decay electron $R_{AA}$ and $v_2$ is challenging.

→ Can provide constraints to energy-loss models.

Similar picture for heavy-flavour decay muons (and D mesons).

TAMU elastic: arXiv: 1401.3817
MC@ sHQ+EPOS, Coll + Rad (LPM): Phys. Rev. C 89 (2014) 014905
CONCLUSIONS

ALICE measurement of HFE $R_{AA}$, $v_2$ in 2.76 TeV Pb-Pb collisions.

$R_{AA}$

- Suppression consistent with in-medium energy loss $\sim 0.4$ in 0-10% and $\sim 0.7$ in 40-50% central Pb-Pb collisions.
- $R_{AA}$ (0-10%) < $R_{AA}$ (40-50%).

$v_2^{HFE}$

- Non zero $v_2$ in 20-40% central Pb-Pb collisions.
- Suggest strong re-interactions of heavy quarks in the QCD medium.
BACK UP
**RAA COMPARISON**

Heavy flavour decay electrons $R_{AA}$

Pb-Pb, $\sqrt{s_{NN}} = 2.76$ TeV, 0-10% central, $|y|<0.6$

- with pp ref. from scaled cross section at $\sqrt{s} = 7$ TeV
- with pp ref. from FONLL calculation at $\sqrt{s} = 2.76$ TeV

0-10% central Pb-Pb

ALICE

$R_{AA}$

0-10% Pb-Pb, $\sqrt{s_{NN}} = 2.76$ TeV

- Charged pions, $|\eta|<0.8$
- Charged particles, $|\eta|<0.8$

- CUJET 3.0
- Djordjevic
- Vitev rad
- WHDG rad+coll
Pb-Pb, $\sqrt{s_{NN}} = 2.76$ TeV

- Average $D^0$, $D^+$, $D^{*-}$, $|y|<0.5$, 0-7.5%
- with pp $p_T$-extrapolated reference
- Charged particles, $|\eta|<0.8$, 0-10%
- Charged pions, $|\eta|<0.8$, 0-10%

Filled markers: pp rescaled reference
Open markers: pp $p_T$-extrapolated or FONLL reference

Empty boxes: syst. uncertainties

Heavy flavor decay $e^\pm$ 0-10%, $|\eta|<0.6$
Heavy flavor decay $\mu^\pm$ 0-10%, 2.5<$$y$$<4.0
**V2 COMPARISON**

V2\textsubscript{EP}, $|\Delta \eta| > 2.0$

ALICE Preliminary 2.76 TeV Pb-Pb, 0-10\% Centrality Class, $|y| < 0.7, |\eta| > 0.9$

Heavy-flavour decay $e^\pm$, $2.5 < y < 4$

$\pi^0$ V2 WHDG LHC Extrapolation

**30-40\%**

**20-40\%**

Pb-Pb, $\sqrt{s_{NN}} = 2.76$ TeV 20-40\% Centrality Class