Azimuthal correlations of heavy-flavor decay electrons and charged particles with the ALICE detector

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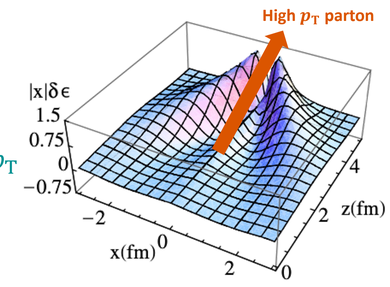
Motivation

- Heavy-Flavor (HF) quarks are produced via hard-scattering in heavy-ion collisions and interact with the quark-gluon plasma (QGP) via elastic and inelastic collisions
- Jets are modified by the medium, which is in turn influenced by them:
  - Medium induced soft-gluon radiation from the traversing heavy quark (gluonsstrahlung)
  - Jet induces Mach-cone-like excitation within the medium
  - Both aforementioned effects could induce an enhancement of low p_{T} hadrons inside the jet
  - Jet quenching of away-side jet
- Heavy-quark interaction with the QGP medium and modification of its fragmentation can be studied using azimuthal correlations of heavy-flavor particles and charged hadrons

G.-Y. Qin et al, PRL 103, 152303 (2009)[1]



Jet "wake" effect from quark-initiated parton shower

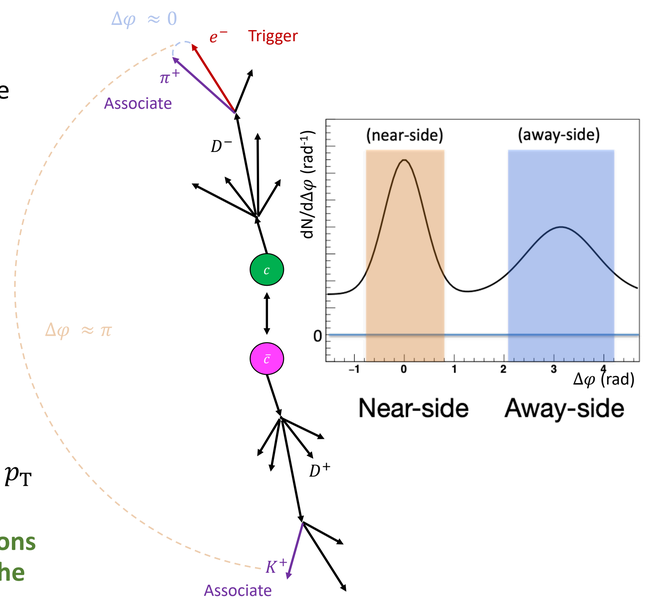
- The nuclear modification factor (I_{AA}) can be used to study the effect of the QGP medium on HF jet fragmentation

- The I_{AA} is defined as the ratio of per-trigger associated yield in Pb—Pb collisions to pp:

$$I_{\mathrm{AA}} = \frac{Y^{\mathrm{Pb-Pb}}_{\Delta\varphi}}{Y^{\mathrm{pp}}_{\Delta\varphi}}$$

Azimuthal correlations

- $\Delta\varphi \equiv \varphi_{\mathrm{Trig}} - \varphi_{\mathrm{Asso}}$
  - φ_{Trig}: Azimuthal angle of trigger particle
  - φ_{Asso}: Azimuthal angle of associated particle
  - Near-side: $\Delta\varphi \approx 0$
  - Away-side: $\Delta\varphi \approx \pi$
- $\Delta\varphi\ (\mathrm{c,b} \to \mathrm{e-h}) \equiv \varphi^{\mathrm{c,b}\to\mathrm{e}}_{\mathrm{Trig}} - \varphi^{\mathrm{ch.part.}}_{\mathrm{Asso}}$
- Near-Side (NS) peak: particles produced in the same jet as the trigger
- Away-Side (AS) peak: particles produced in the recoil jet
- **Trigger particle (c, b → e)** is selected:
  $4 < p_{\mathrm{T}} < 12$ (GeV/c)
- **Associated (charged) particles** are selected in 5 p_{T} ranges: from **1 to 7 (GeV/c)**
- **This analysis was performed on Pb—Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV and collected by ALICE in the centrality classes 0 – 10% and 30 – 50%**

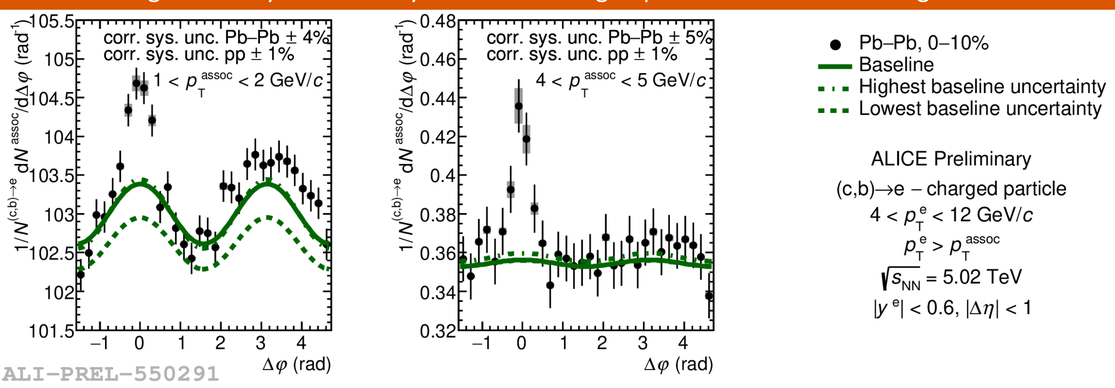


Analysis strategy with the ALICE detector

Electron identification (EID) → Build 2D ($\Delta\varphi$, $\Delta\eta$) correlation → Correct 2D correlation for efficiency and acceptance effects → Remove electrons not from HF sources → Project to $\Delta\varphi$; Fit uncorrelated background → Subtract uncorrelated pairs

- EID performed using TPC and EMCal; hadron contamination is subtracted
- 2D ($\Delta\varphi$, $\Delta\eta$) distribution between electron and charged hadrons is constructed
- Detector acceptance effects on 2D distribution corrected by using mixed-event technique
- Project 2D distribution to 1D $\Delta\varphi$ for $|\Delta\eta| < 1$
- Contribution of electrons not from HF sources ($\gamma \to e^-e^+; \eta, \pi^0 \to e^-e^+$) is reconstructed with invariant-mass method via unlike-sign (ULS) electron pairs
  - Tagging efficiency applied to correct unidentified photonic and Dalitz-produced electron contribution
- $\Delta\varphi$ distribution corrected with associated hadron tracking efficiency and secondary particle contamination factor

Fitting the heavy-flavor decay electron—charged particle correlation background

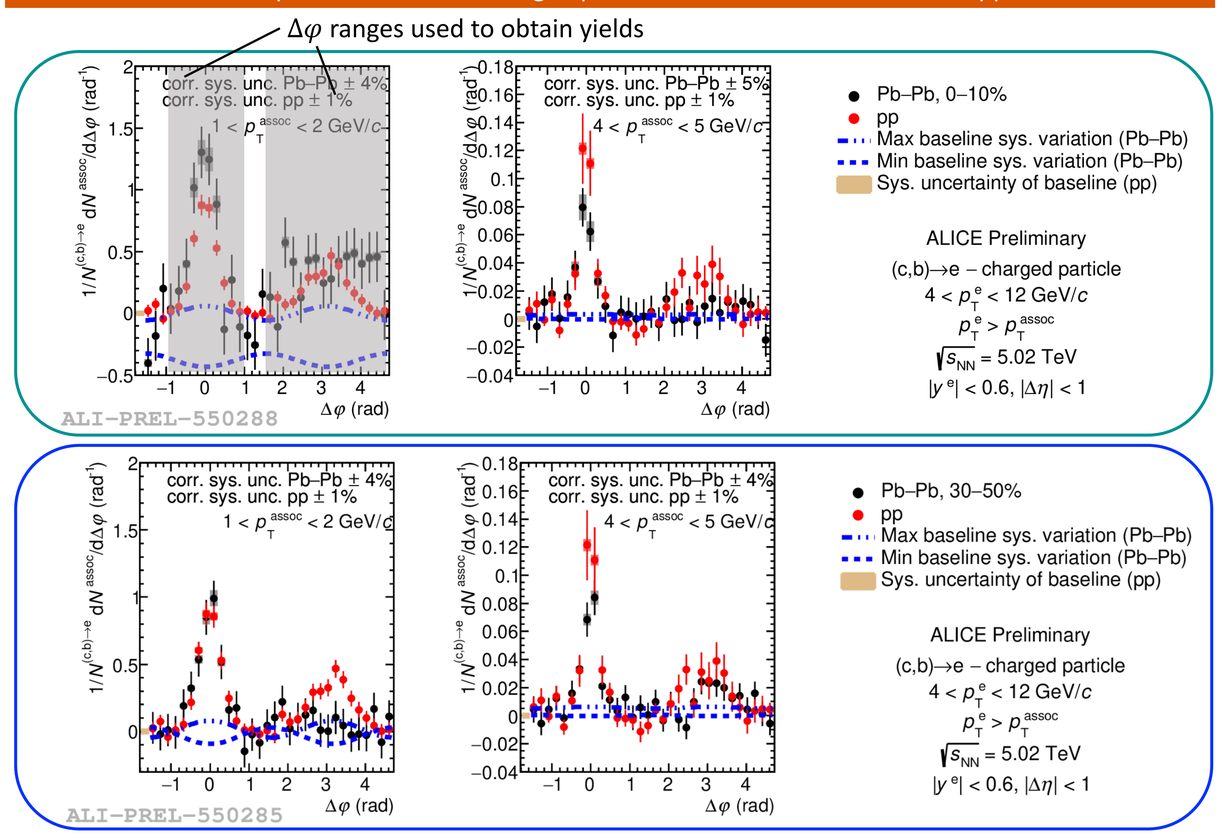


- $\Delta\varphi$ c, b → e — charged particle distribution, normalized per heavy-flavor electron trigger in 0 – 10% centrality
- Baseline function $B(\Delta\varphi)$ is used to parameterize the uncorrelated background in the transverse region (including a modulation induced by elliptic flow):

$$B(\Delta\varphi) = b\left(1 + 2v_2^{\mathrm{c,b}\to\mathrm{e}} v_2^{\mathrm{ch.part.}}\right)\cos(2\Delta\varphi)^{4,5}$$

- Variations of the possible baseline position take into account alternate values of pedestal (b) and the minimum and maximum measured v_2 values

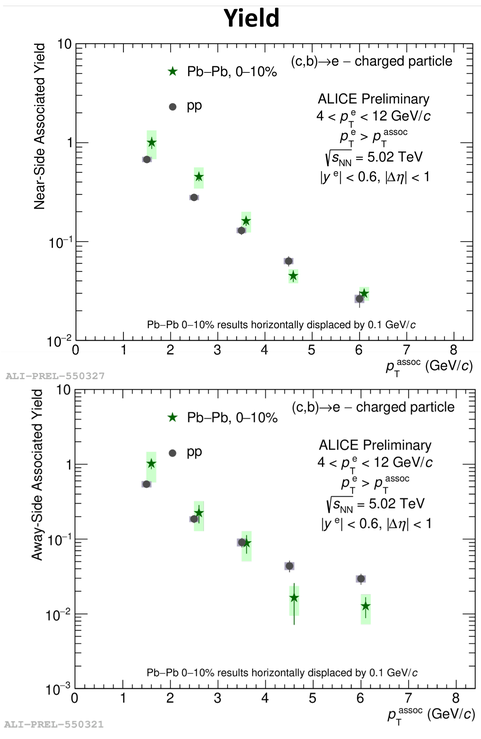
Heavy-flavor electron—charged particle correlations in Pb—Pb and pp



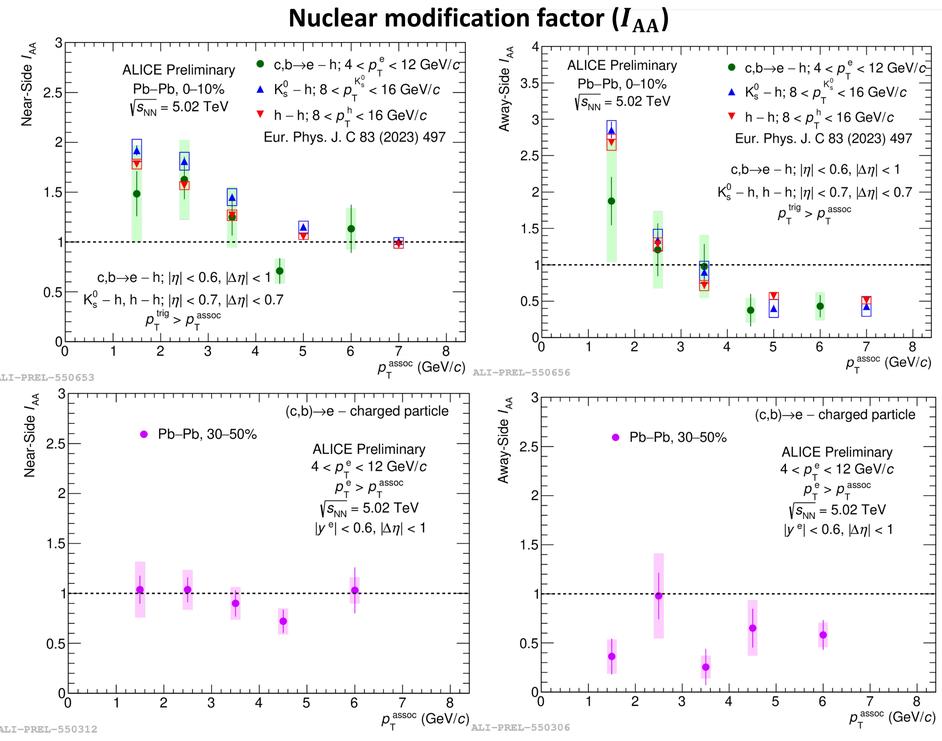
- (Top) $\Delta\varphi$ c, b → e — charged particle correlation in **0 – 10%** centrality after baseline subtraction and compared to pp
  - NS peak is qualitatively higher in Pb—Pb at low p_{T} compared to pp; similar to pp at high p_{T}
  - AS peak appears higher and broader at low p_{T}; suppressed at high p_{T} compared to pp
- (Bottom) $\Delta\varphi$ c, b → e — charged particle correlation in **30 – 50%** centrality compared to pp[2]
  - NS peaks in Pb—Pb similar to pp
  - AS peaks in Pb—Pb suppressed compared to pp

Results

Yield



Nuclear modification factor (I_{AA})



- **Per-trigger associated yield:**
  - Obtained by integrating the distributions in the NS region $|\Delta\varphi| < 1$ and AS region $|\Delta\varphi - \pi| < 1.5$
  - Yield decreases as a function of associate p_{T} for both NS and AS, as well as for Pb—Pb and pp
  - These differences between pp and Pb—Pb are better quantified with the I_{AA} observable

I_{AA} 0 – 10%:

- NS: No significant enhancement at low p_{T} due to large uncertainties
  - Combined significance of 1.31σ above 1 for $1 < p_{\mathrm{T}} < 3$ GeV/c
  - Fluctuates about unity at higher p_{T}
- AS: Hint of suppression at high p_{T}
  - Significance of $\sim 2.5\sigma$ for $I_{\mathrm{AA}} < 1$ for $p_{\mathrm{T}} > 4$ GeV/c

I_{AA} 30 – 50%:

- NS: Consistent with unity for all p_{T}
- AS: Data fluctuate within large uncertainties but point towards a suppression

Physics process that can produce these effects in the I_{AA}

- Gluon emission from quark fragmentation
- Jet-induced medium response at low p_{T}
- Jet-quenching in AS due to surface bias at high p_{T}

Comparison of heavy-flavor with light-flavor

- 0 – 10% I_{AA} comparison made with light-flavor (LF) di-hadron and K^0_s — h correlations[3]
- Fundamental differences between the two observables
  - LF mainly originate from gluon jets
  - c, b → e originates from heavy quark jets
- **Although $\Delta\varphi$ c, b → e — h has large uncertainties, the I_{AA} follows similar associated p_{T} trends and has consistent values with LF I_{AA} for both NS and AS**

Summary

- c, b → e — h azimuthal correlations were obtained in 0 – 10% and 30 – 50% Pb—Pb at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV
- $\Delta\varphi$ distributions NS and AS yield compared between Pb—Pb and pp
- The NS and AS **I_{AA} consistent with LF within large uncertainties** in 0 – 10% Pb—Pb collisions
- **Possible suppression of high p_{T} particles** on the AS for both centralities
- NS I_{AA} consistent with unity for 30 – 50%
- Future prospects for Run 3:
  - Larger data sample and improved technique to reduce systematic uncertainties for c, b → e — h correlation
  - Azimuthal correlations of D meson — charged particles and c, b → e — D mesons

References
1: G.-Y. Qin et al, PRL 103, 152303 (2009)
2: EPJ C 83 (2023) 741
3: EPJ C 83 (2023) 497
4: JHEP 07 (2018) 103 (ALICE)
5: Phys. Lett. B 807 (2020) 135595 (ATLAS)