Separation of heavy-flavour decay muons with the ALICE Muon Forward Tracker (MFT)

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Physics motivation

- ❑ Heavy flavours (HF), mesons or baryons containing one or more heavy quarks (c,b), are crucial probes of the properties of quark-gluon plasma (QGP), produced in heavy-ion collisions.
- ❑ Heavy quarks are produced in hard scattering processes during the early stages of heavy-ion collisions and the hadrons produced after the hadronisation subsequently decay into particles as muons and electrons.
- ❑ The study of heavy quark interactions with QGP provides insights into the properties of this medium and a better understanding of particle behavior in extreme conditions.
- ❑ In ALICE, muons are detected by the forward muon spectrometer and the Muon Forward Tracker (MFT).

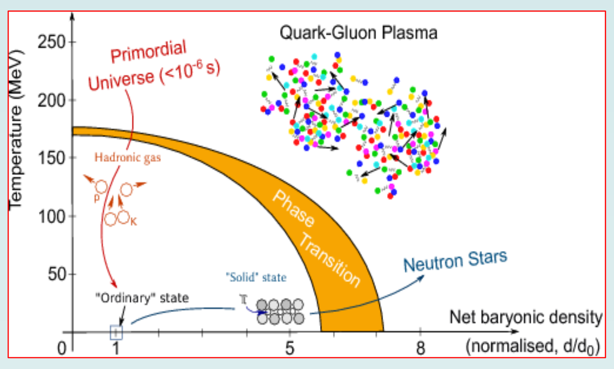


Figure 1: QGP state in QCD phase diagram

- ✓ Muons from HF decays are identified based on kinematic criteria such as momentum and the distance of the closest approach (DCA) to enable a more detailed study of HF interactions with the QGP.
- ✓ The beauty contribution (from B meson decays) to the muon yield needs to be separated from the charm (from D mesons) component for in-depth studies of charm and beauty dynamics in the of QGP.
- ✓ Precise muon track reconstruction in the vicinity of the interaction vertex is a crucial step for separating the beauty and charm contributions in pp and Pb-Pb collisions.
- ✓ The separation of these contributions provides important information on the c and b quark interactions in the QGP.
- ✓ It also allows for experimental investigations into the mass and color charge dependencies of energy loss of heavy quarks, light quarks, and gluons.

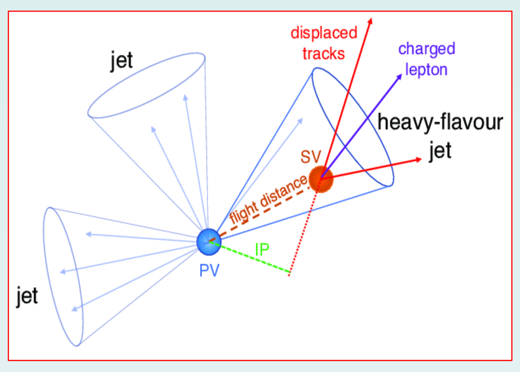


Figure 2: Lepton (μ,e⁻) production from secondary vertex

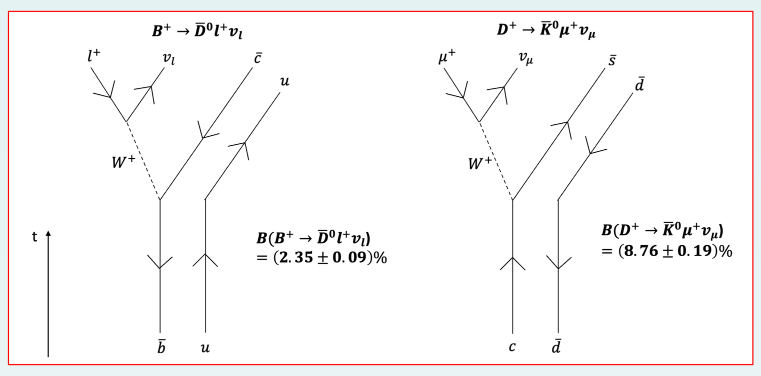


Figure 3: Major decay channel

Muon Forward Tracker (MFT)

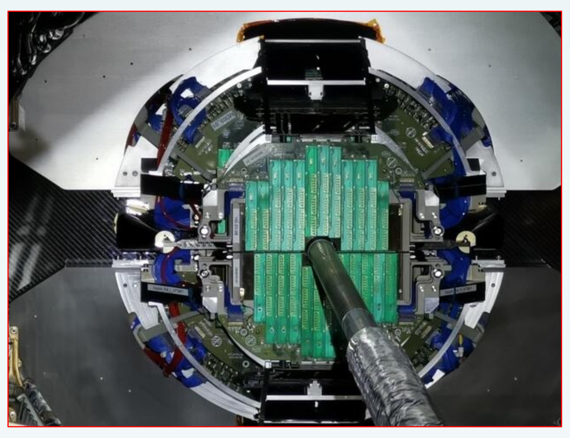


Figure 4: MFT half-disks

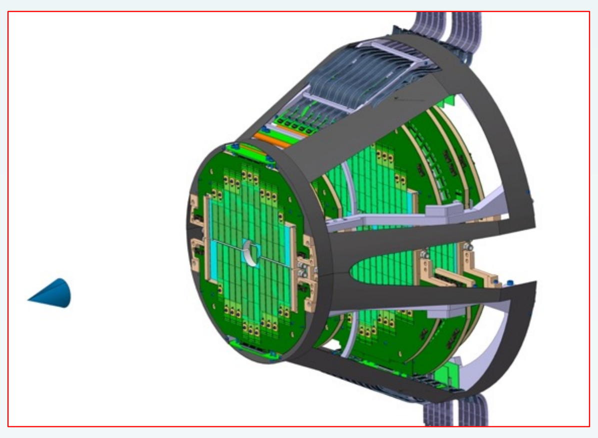


Figure 5: MFT geometry

- ❑ Designed to reconstruct the trajectories of muons emitted at forward angles in heavy-ion collisions.
- ❑ Has a coverage of $-3.6 < \eta < -2.5$ and a full azimuthal angle coverage.
- ❑ High resolution silicon-tracking detector made of two half cones, each consisting of five half-disks positioned along the beam axis between -46 cm and -76.8 cm from the interaction point.
- ❑ MFT can be used in c/b muon separation by detecting the passage of charged particles and providing information on the distance of closest approach of the muon track from the primary vertex.

ALICE Analysis Framework

- ❑ In the LHC Run 3, the O² framework is used for simulations and analysis, with a specific emphasis on the decay of heavy flavor hadrons, such as the decay of B and D mesons into muons (B,D→μX).
- ❑ For the performance studies, HIJING is used to simulate the background (mainly composed of π, K) and the signals from a PYTHIA parametrisation are embedded in HIJING events.
- ❑ The GEANT 4 detector simulation software providing an accurate representation of the experimental setup, is used to simulate the interaction of the generated particles with the ALICE detector.

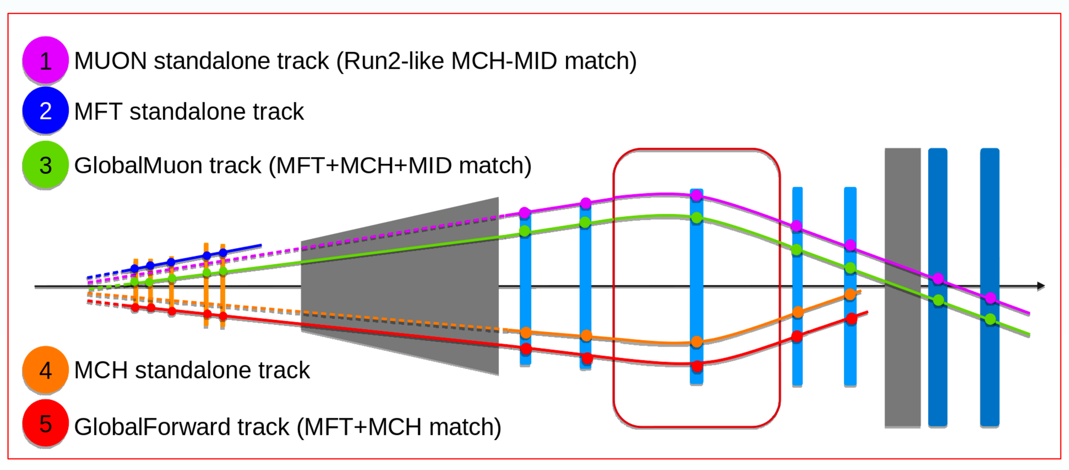


Figure 6: Track reconstruction in the Muon spectrometer and MFT

- ❑ The DCA (or impact parameter) is a quantity used to describe the minimum distance between the trajectory of a particle and a given point, typically the primary interaction vertex.
- ❑ More specifically, it corresponds to the minimum distance between the particle's path and the vertex in the transverse plane.
- ❑ The DCA_T calculation projects muons trajectories from B and D meson decay onto the xy-plane. The simulation parameters include information about the decay point (DP), rapidity (η), and azimuthal angle (φ), which are used in the DCA_T calculation.

Performance studies

❖ The inclusive muon yield is mainly composed of:

1) muons from charm and beauty hadron decays (the signals).
2) muons from light-flavour hadron (π, K) decays at low p_T.
3) muons from W, Z/γ* decays at high p_T (p_T > 15 GeV/c).

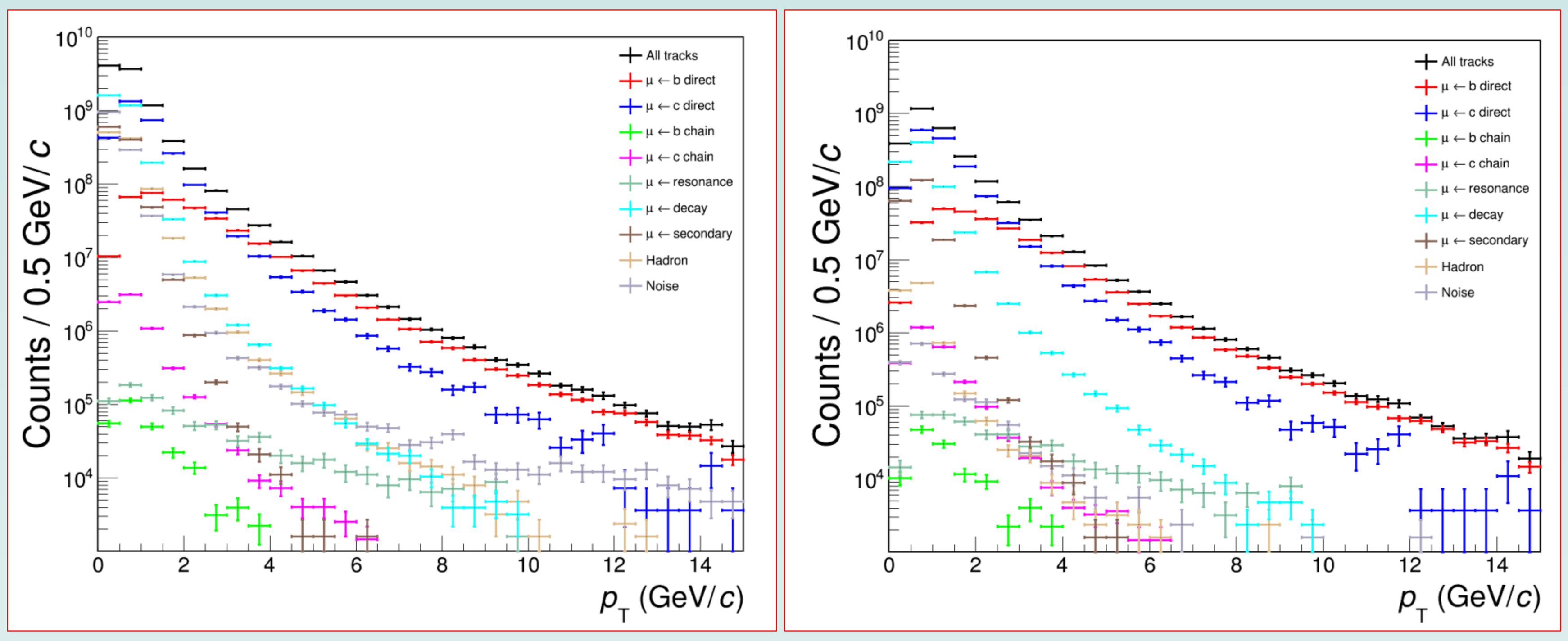
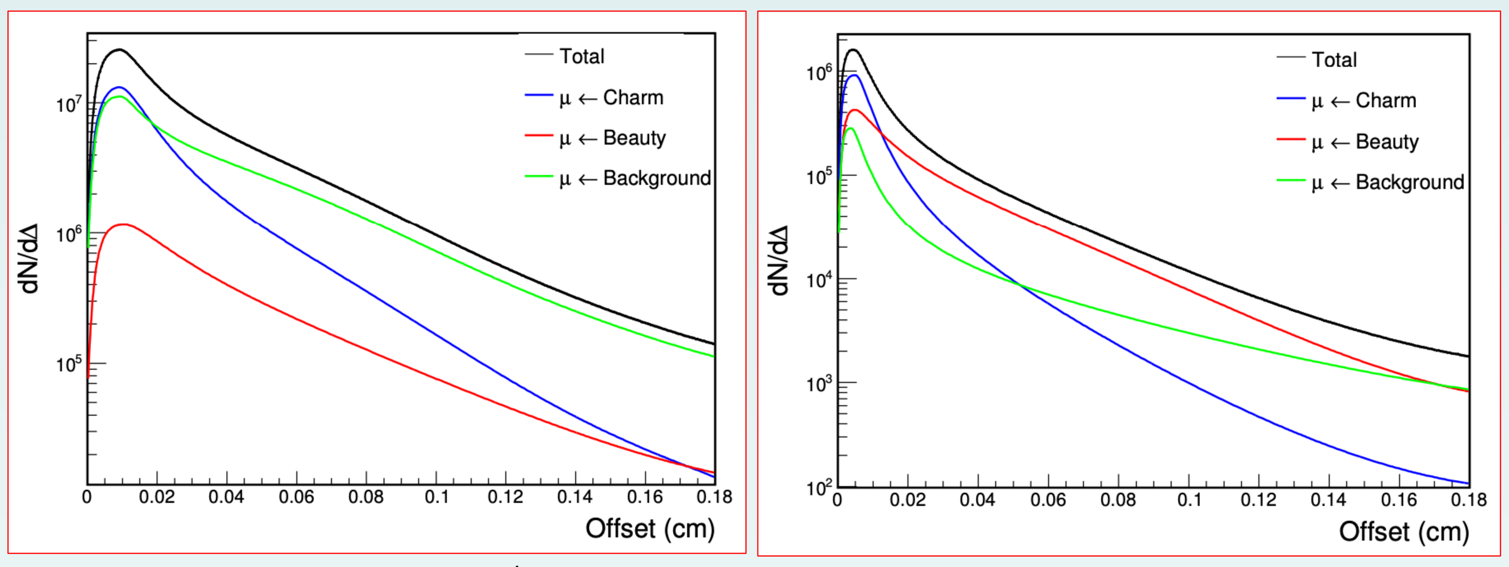


Figure 7: Single muon reconstructed p_T distribution without (left) and with (right) muon selection cuts for Pb-Pb collisions at 5.5 TeV. The normalisations are relative to an integrated luminosity of 10 nb⁻¹

Offset: $\Delta = \sqrt{(x_V - x_{Extrap})^2 + (y_V - y_{Extrap})^2}$

(x_V,y_V) : the transverse coordinates of the primary vertex measured by the Inner Tracking System (ITS)
(x_{Extrap},y_{Extrap}) : the coordinates in the plane transverse to the beam line of the extrapolated track evaluated at the z of the primary vertex.



1.0 < p_T < 1.5 GeV/c　　4 < p_T < 6 GeV/c

Figure 8: Result of the combined fit of the offset distribution of the main muon sources adjusted with a variable-width Gaussian function at low p_T (0.5 < p_T < 1 GeV/c, left) and high p_T (4 < p_T < 6 GeV/c, right).

- ❑ Offset and DCA, along with further kinematic quantities, can be used to estimate the decay length of B and D mesons, which is related to their lifetime.

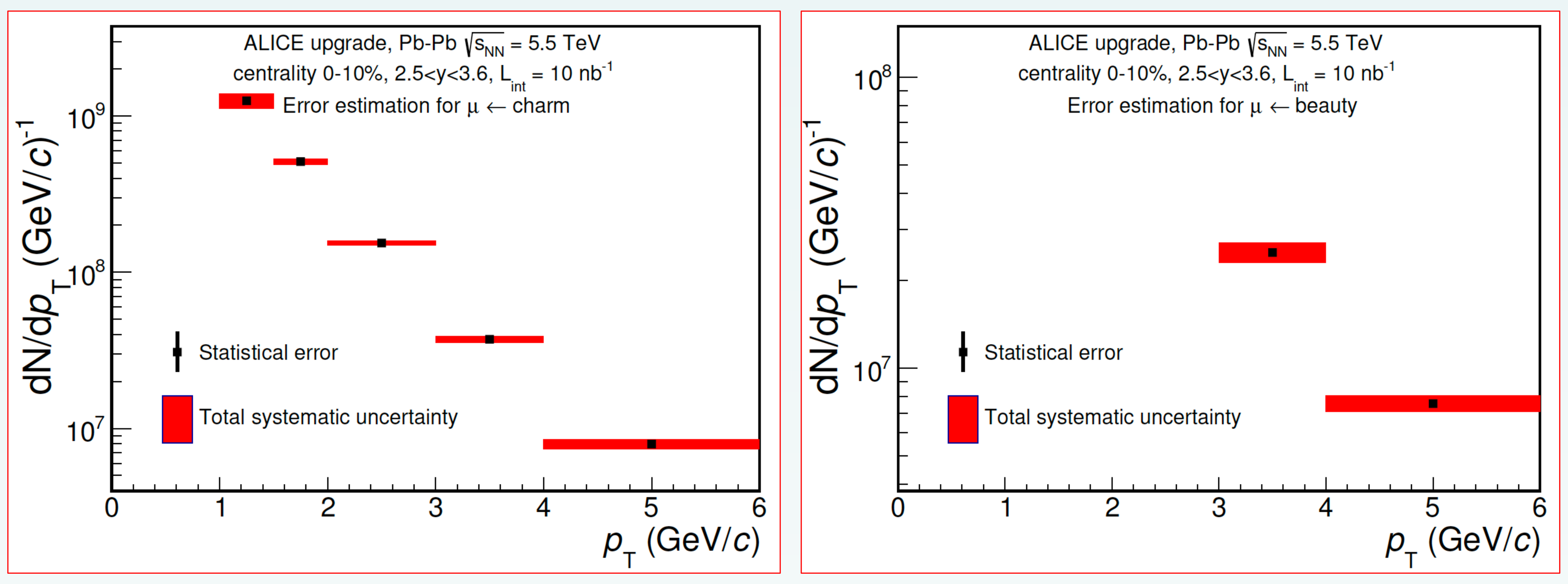


Figure 9: Expected p_T distributions of single muons from charm (left) and beauty (right) decays with their respective statistical and systematic uncertainties

- ✓ The analysis strategy for the measurement of the charm and beauty yields in the single muon channel, is based on the fit of the offset distribution Δ.
- ✓ The max of Δ is shifted towards lower Δ at high p_T.
- ✓ Δ distributions of the various sources:

1) at low p_T: muons from π, K decays are the main contribution over the whole Δ distribution.
2) at high p_T: muons from charm-hadron decays dominate for small Δ values and muons from beauty-hadron decays dominate at large Δ.

❖ Measurement of B→μ complements the measurement of J/ψ coming from the decay of B hadrons.

Conclusion and Outlook

- ➢ MFT provides vertexing capabilities at forward rapidity.
- ➢ Muons from charm-hadron decays and beauty-hadron decays can be separated from the light-flavour background down to about 0.5 GeV/c and 2 GeV/c, respectively.
- ➢ Muons from the decays of beauty hadrons have a larger average separation from the primary vertex than those from charmed hadrons due to their longer lifetime of beauty hadrons.
- ➢ Promising performance studies: separation of muons from charm and beauty decays can performed at forward rapidity in the LHC Run 3 data.
- ➢ Analysis of pp collisions at 13.6 TeV collected in 2022 is ongoing. Data taking of Pb-Pb collisions at 5.36 TeV expected in October 2023.

More to come soon.

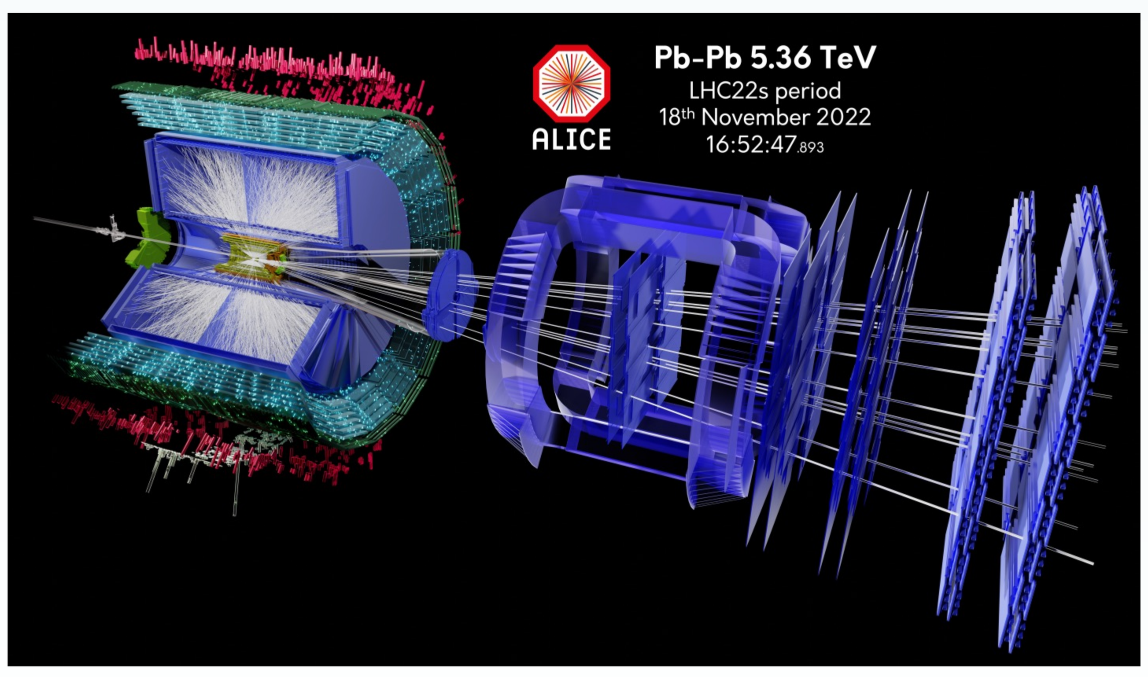


Figure 10: ALICE event display of a first Pb-Pb collision at 5.36 TeV collected during the Run 3 in November 2022

References

[1] ALICE, Addendum of the Letter of Intent for the upgrade of the ALICE experiment : The Muon Forward Tracker, CERN-LHCC-2013-014 ; LHCC-I-022-ADD-1 (2013)
[2] ALICE Collaboration. (2018). The ALICE experiment at the CERN LHC. Journal of Instrumentation, 13(08), P08003.
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