Heavy flavor measurements with the ALICE detector at the LHC

R. Guernane (LPSC Grenoble CNRS/IN2P3–UGA) TOSHIKO YUASA LABORATOR ON behalf of the [ALICE-HF] Project FJKPPN Workshop May 14–16, 2025 Nantes, France



- Charm and beauty quarks have large masses: $m_{\rm c} \sim 1.3 \text{ GeV/c}^2$, $m_{\rm b} \sim 4.2 \text{ GeV/c}^2$
 - Produced in initial hard scatterings with large transferred momentum Q^2
 - $m_{c,b} \gg \Lambda_{QCD} \Rightarrow$ production calculable within pQCD
 - $\tau(\text{HF}) \leq 0.1 \text{ fm/}c < \tau(\text{QGP}_{\text{form., LHC}}) \approx 0.3 \text{ fm/}c \text{ (PRC 89 (2014) 034906)}$
- Interesting probes in different collision systems
 - pp collisions: test of pQCD-based models
 - Heavy quarks production
 - Hadronisation
 - Parton Distribution Functions (PDFs)
 - Reference for heavy-ion collisions
 - Heavy-ion collisions
 - Heavy quarks transport
 - Thermalisation
 - Energy loss in the QGP
 - Colour-charge and quark-mass dependence
 - Modification of hadronisation





ALICE-HF project overview



- Focus on Run 3 data analysis
- Exclusive reconstruction of hadronic decays
 - Charm-baryon production measurements in pp, pPb, and Pb–Pb collisions
 - Measurement of Ξ_c^+ baryon via hadronic decay channel in pp collisions at 13 TeV and 13.6 TeV, Jaeyoon Cho Inha Univ.
 - Measurement of multiplicity dependent Ξ_c^0 via semileptonic decay channel in pp collisions at 13 TeV, Jinhyun Park Pusan Nat. Univ.
 - Beauty-meson production in pp collisions at 13.6 TeV
 - Exclusive reconstruction of B0 mesons in the $B^0 \rightarrow D^- \pi^+ \rightarrow \pi^- K^+ \pi^- \pi^+$ decay channel, Alexandre Bigot IPHC
- (Heavy-flavor) jets
 - Charged-jet measurements in pp collisions at 13.6 TeV and Pb–Pb collisions at 5.36 TeV, Joonsuk Bae SKKU, Aimeric Landou LPSC
 - Jets tagged with heavy-flavor quarks in pp collisions allow us to investigate the evolution of quark-initiated parton showers, Vit Kucera Inha Univ
 - b-tagging algorithms, Clément Lotteau IP2I, Hyungjun Lee SKKU, Changhwan Choi Pusan Nat. Univ.

ALICE physics performance in Run 3 GRENOBLE | MODANI



• LS2 (2019–2021) major upgrades of the ALICE detector

- Continuous readout (up to 500 kHz in pp and 50 kHz in Pb–Pb)
 - Selection of interesting physics events
 using high-level offline trigger selections
 - Larger data samples
- Improved pointing resolution at midrapidity by a factor of 3 (6) in the transverse plane (beam-line) direction) compared to Run 2
- Careful consideration of new challenges introduced by continuous readout
- Continued progress in understanding new detector behaviour





Run 3 data taking







Large pp samples collected (with offline trigger selections) 2025 data taking progressing very well

Large heavy-ion data sample collected in 2023 (1.6 nb⁻¹, approx. 11.5 G min. bias events, \times 30 more as compared to Run 2); first results shown at conferences

B⁰ meso reconstruction

ALICE



 First observation of fully reconstructed open-beauty hadrons with ALICE

- Exclusive reconstruction of B^0 mesons in the $B^0 \rightarrow D^- \pi^+ \rightarrow \pi^- K^+ \pi^- \pi^+$ decay channel
 - B^0 candidates are built by combining a D^- candidate with a displaced charged pion
 - Raw signal extracted from a fit to the invariant mass distribution of selected candidates
 - BDTs used to
 - Enhance the contribution from non-prompt D^-
 - Separate signal/background *B*⁰ candidates
- Results presented at QM 2025
- Used as basis for future B⁰-tagged jet measurements to be investigated w/i the ALICE-HF project



RENOBLE I MODAN

B⁰ meso reconstruction

ALICE



• First observation of fully reconstructed open-beauty hadrons with ALICE

- Exclusive reconstruction of B^0 mesons in the $B^0 \rightarrow D^-\pi^+ \rightarrow \pi^- K^+\pi^-\pi^+$ decay channel
 - B^0 candidates are built by combining a D^- candidate with a displaced charged pion
 - Raw signal extracted from a fit to the invariant mass distribution of selected candidates
 - BDTs used to
 - Enhance the contribution from non-prompt D^-
 - Separate signal/background *B*⁰ candidates
- Results presented at QM 2025
- Used as basis for future B⁰-tagged jet measurements to be investigated w/i the ALICE-HF project



RENOBLE I MODAN



Charm-baryon measurements

MeV/c

Counts



- Multiplicity dependent $\Xi_{c}^{0,+}$ production in pp collisions at 13 TeV
 - BDT algorithm to select Ξ_c^+ candidates
 - Results presented at SQM 2024
- First studies of charm-baryon reconstruction using the large data sample of pp collisions at 13.6 TeV
- Used as basis for future $\Xi_c^{0,+}$ tagged jet measurements to be investigated w/i the ALICE-HF project







Charm-baryon measurements



- Multiplicity dependent
 \vec{E}_{c}^{0,+} production in pp collisions at 13 TeV
 - BDT algorithm to select Ξ_c^+ candidates
 - Results presented at SQM 2024
- First studies of charm-baryon reconstruction using the large data sample of pp collisions at 13.6 TeV
- Used as basis for future E^{0,+}tagged jet measurements to be investigated w/i the ALICE-HF project



Investigation of charm-quark hadronisation into baryons in hadronic collisions with ALICE Award for the best experimental talk at SQM 2024 conference, June 3–7 2024, Strasbourg





- Multiplicity dependent
 \(\mathbf{E}_c^{0,+}\) production in pp collisions at 13 TeV
 - BDT algorithm to select Ξ_c^+ candidates
 - Results presented at SQM 2024
- First studies of charm-baryon reconstruction using the large data sample of pp collisions at 13.6 TeV
- Used as basis for future \(\mathbf{E}_c^{0,+}\)tagged jet measurements to be investigated w/i the ALICE-HF project





8

Charged-jet in pp collisions





- First charged-jet spectrum measurement with Run 3 data
 - Unfolding of detector effects
 - Consistent with the same measurement performed at 13 TeV
 - Comparison to pQCD-based models
 - Results presented at HP 2024
- Next Steps
 - UE subtraction
 - Reducing systematics
 - Van Der Meer scans will reduce the error on the luminosity which is currently significant
 - Vary R
 - Multiplicity dependence
 - Study jet quenching in extremely high multiplicity pp events, e.g. 0.1% highest multiplicity



Charged-jet in Pb–Pb collisions



- Measurement of the jet R_{AA}
 - Take full advantage of the large collected statistics to perform more differential measurements
 - R_{AA} as a function of jet substructure to explore the role of colour coherence in energy loss
 - Results presented at HP 2024
 - pp reference data collected in Nov 2024 now being analysed









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



Flavour tagging

 Designed to reconstruct the characteristic features of b-jets exploiting the large impact parameters of the tracks originating from the b-hadron decays

tracks

b hadron

impact parameter

do

~

light jet



Central Pb+Pb collisi

Seffects radiative E-lose



IP-based b-tagging



 Sa_{xy}

- IP and its significance S_{IP} are signed w.r.t jet direction
 - Count tracks with: $|S_{IP}| > cut$







15

ALICE Upgrade Roadmap



- ALICE designed to study the microscopic dynamics of the strongly-interacting matter produced in heavy-ion collisions at the LHC
 - Variety of detector systems for measuring hadrons, leptons and photons
- To exploit the full potential of the LHC luminosity increase
 - Major upgrade during LHC LS2 \rightarrow **ALICE 2**

Outline





- Improvement by a **factor 2** on DCA resolution at all p_{T} 's
 - Clear **separation** of the secondary from primary interaction vertex
- Significant improvement of **tracking efficiency** for $p_T < 200 \text{ MeV}/c$
- New fundamental observables into reach
 - Charmed and beauty baryons
 - Low-mass di-electrons
 - Multi-flavour particles via decays to strange baryons
 - Full topological reconstruction of B_s
 - c-deuterons...

16





- Reduce the material thickness of the ITS2 inner layers
 - The silicon sensor contributes to only 1/7th of the total material budget!
 - Remove the **electrical substrate**, **mechanical support**, and active **cooling** circuit in the detector acceptance
- Bring the first detection layer closer to the interaction point
 - New beam pipe with a central section of smaller inner radius (18.2 mm → 16 mm) but still well within the LHC aperture requirements







 ϕ (rad)

Aluminum (14.3%) Glue (5.3%)



ITS3 Detector





- Replace the 3 innermost layers of ITS2 with new ultra-light, truly cylindrical layers made of wafer-scale 65 nm MAPS
 - 300 mm wafer-scale MAPS sensors, fabricated using stitching
 - Bent to the target radii (Layer 0 from 23 mm to 19 mm)
 - Mechanically held in place by carbon foam ribs
 - Air cooling between the layers
 - Low material budget (0.05 % of X_0)
- Broad interest on ALICE ITS3 developments from other experiments!
 - ITS3 R&D will pave the way for an **ultimate vertex detector concept** \rightarrow ALICE 3

ALICE Asian France Workshop

- Lyon, 13–15 Jul 2024
- 26 participants
- Rich agenda covering current and future topics
 - Large audience given to PhD students and postdocs
 - Foster joint activities
 - Many avenues!



Heavy and
light-flavour
hadrons and
Theory

Welcome	Rachid Guernane et al.	Ø
CISL Centre International de Séjour de Lyon	14:00 - 14	:15
Study of f0(980) and f2(1270) particles with Run 3 data	Beomkyu Kim	Ø
CISL Centre International de Séjour de Lyon	14:15 - 14	:45
Multiplicity-dependent $ ho$ (770)0 production in pp collisions at \sqrt{s} = 13 TeV with ALICE	Hyunji Lim	0
CISL Centre International de Séjour de Lyon	14:45 - 15	:15
Possible studies with light flavour resonance particles	Su-Jeong Ji	Ø
CISL Centre International de Séjour de Lyon	15:15 - 15	:45
Numerical calculation of meson mass using two-body Dirac equation at finite temperature	Younghoo Hong	Ø
CISL Centre International de Séjour de Lyon	15:45 - 16	:05
Coffee beak		
CISL Centre International de Séjour de Lyon	16:05 - 16	:35
Study of charm-quark hadronization into baryons with ALICE	Jaeyoon Cho	0
CISL Centre International de Séjour de Lyon	16:35 - 17	:05
First attempt to reconstruct B0 meson in pp 2022 data	Alexandre BIGOT et al.	Ø
CISL Centre International de Séjour de Lyon	17:05 - 17	:25
Multiplicity dependent production of electrons from beauty-hadron decays in pp collisions a	tt 13 TeV Jonghan Park	0
CISL Centre International de Séjour de Lyon	17:25 - 17	:55
Isolated photon measurements in pp, p–Pb and Pb–Pb collisions	Gustavo Conesa Balbastre	Ø
CISL Centre International de Séjour de Lyon	17:55 - 18	:25

Jet physics

Summary of recent jet results and open questions	Yaxian Mao et al. 🥝
CISL Centre International de Séjour de Lyon	09:00 - 09:30
Ideas and prospects for jet measurements in Run 3	Jaime Norman 🥝
CISL Centre International de Séjour de Lyon	09:30 - 10:00
Track selection and jet spectrum measurement in Run 3	Aimeric Landou 🥝
CISL Centre International de Séjour de Lyon	10:00 - 10:20
Charged-jet measurement in Pb–Pb collisons at 5.36 TeV	Wenhui Feng 🥝
CISL Centre International de Séjour de Lyon	10:20 - 10:40
Coffee break	
CISL Centre International de Séjour de Lyon	10:40 - 11:10
HF-jet perspectives (title TBC)	Vit Kucera 🥝
CISL Centre International de Séjour de Lyon	11:10 - 11:40
b-jet tagging: past, present and future possible measurements	Hadi Hassan 🥝
CISL Centre International de Séjour de Lyon	11:40 - 12:10
b-jet tagging via track impact parameter in pp collisions at 13.6 TeV	Hanseo Park 🥝
CISL Centre International de Séjour de Lyon	12:10 - 12:30
b-jet tagging with Graph Neural Network	Changhwan Choi 🥝
CISL Centre International de Séjour de Lyon	12:30 - 12:50

ALICE Phase 2b upgrades

Physics programme of the ALICE 3 experiment for the LHC Runs 5 and 6	Antonio Uras	
CISL Centre International de Séjour de Lyon	14:00 - 14:40	
Perspectives on ALICE 3 (Outer Tracker project in the ALICE3 context, Scenario 3 of the scoping document)		
Antonin Maire		
CISL Centre International de Séjour de Lyon	14:40 - 15:40	
Coffee break		
CISL Centre International de Séjour de Lyon	15:40 - 16:10	
ALICE 3 related activities in Japan Ye	orito Yamaguchi 🦉	
CISL Centre International de Séjour de Lyon	16:10 - 16:40	
Korean perspectives on ALICE 3	Min Jung Kweon	
CISL Centre International de Séjour de Lyon	16:40 - 17:10	
Closing Rachid	Guernane et al. 🥝	
CISL Centre International de Séjour de Lyon	17:10 - 17:30	







- Run 3 data analysis w/i the ALICE-HF project running full steam!
 - Stay on track for the upcoming year keeping a perspective on longer-term goals which should emerge from this project
 - Substructure of charm and beauty jets

 \Rightarrow Low p_{T} : dead-cone effect for charm vs beauty

 \Rightarrow High p_{T} : Casimir colour factors for quarks vs gluons

- ALICE' upgrade program beyond LHC Run 3, Inha Univ., PNU, SKKU, IPHC, LPSC, IP2I
 - LS3 (2026–2028): new upgrades for LHC Run 4
 - ITS3: truly cylindrical silicon layers made of ultra-thin wafer-size MAPS
 - Improve heavy flavour particle performance
 - Beyond Run 4: continue the heavy-ion programme during the HL-LHC era
 - Proposal of a new experiment ALICE 3 with "nearly-massless" tracker installed during LS4
 - Multi-charm and beauty particles