Heavy flavor production and flow in large and small systems with ATLAS

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Motivation



- Large mass
- Most from hard scattering, pQCD calculable

- (Traditionally) baseline for understand A+A collisions
- Probing small QGP drop in small systems



Heavy flavors (HF) probes are unique for studying QGP in A+A collisions:

Heavy flavors in *p*+A / *pp* collisions:

0-10% Pb+Pb

HF muons

Momentum imbalance $\Delta p = p_{\text{ID}} - (p_{\text{MS}} + p_{\text{Calo}})$

template fit











HF muons

Momentum imbalance $\Delta p = p_{\text{ID}} - (p_{\text{MS}} + p_{\text{Calo}})$ template fit

bottom to charm ratio in pp by FONLL

0-10% Pb+Pb



$$D^0 \rightarrow K\pi$$

- **Event collected by MinBias trigger**
- Dominated by open charm contribution

EPJC 78 (2018) 171

- <u>HF muon yield and flow in 2.76 TeV Pb+Pb</u> • HF muon flow in 8.16 TeV p+Pb prelim. <u>D meson yield and flow in 8.16 TeV p+Pb</u> prelim. • Non-prompt J/ ψ yield in 5.02 TeV Pb+Pb prelim. • Non-prompt J/ψ flow in 5.02 TeV Pb+Pb • Non-prompt J/ ψ yield in 5.02 TeV p+Pb
- HF muon (Open Charm + Beauty) D meson (Open Charm) Non-prompt J/ ψ (Open Beauty)

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- HF muon (Open Charm + Beauty) D meson (Open Charm) Non-prompt J/ ψ (Open Beauty)

New or updated since last QM

HF muon RAA in Pb+Pb

- Significant suppression ~ 0.4 in most central
- Strong centrality dependence. No significant dependence on p_T

HF muon R_{AA} measured in 5 centrality slices covers 0-60%

HF muon Raa in Pb+Pb

ATLAS vs. ALICE

Good agreement \bigcirc

HF muon RAA in Pb+Pb

ATLAS vs. ALICE

Good agreement \bigcirc

ATLAS HF muon vs. CMS prompt D⁰

- Similar at low p_T
- Less suppression of HF muon at higher p_T

HF muon v_2 in Pb+Pb

- v_2 is extracted based on event plane method, good consistency with scalar product method
- Combinatorial background is subtracted by momentum imbalance template fits
- Significant v_2 observed with high precisions in all centralities

HF muon R_{AA} and v_2 vs calculations

DABMod (energy-loss model with event-byevent fluctuations) gives a good description of v_2 but underestimates R_{AA} at low p_T due to incomplete modeling of low p_T heavy-flavor suppression

TAMU (transport model) describes the feature of data R_{AA} , but slightly underestimates v_2

> arXiv: 1805.05220 TAMU: PLB 735 (2014) 445 DABMod: PRC 96 (2017) 064903

Non-prompt J/ψ in Pb+Pb

Strong suppression in Pb+Pb collisions, small cold nuclear matter effects

 v_2 is extracted from event plane method, non-zero v_2 observed

See Jorge's talk on Monday 16:50

arXiv: 1805.04077 **ATLAS-CONF-2018-013**

Non-prompt J/ ψ vs. HF muon

R_{AA}

Smiliar suppression and flow for HF muon and non-prompt J/ ψ at p_T > 9 GeV

arXiv: 1805.05220 arXiv: 1805.04077 ATLAS-CONF-2018-013

- Prompt D^0 with $3 < p_T < 30$ GeV
- FONLL prediction at 8 TeV scaled by A_{Pb}
- Data and FONLL agree within uncertainties

Prompt D⁰

- Forward: 0 < y* < 0.5, Backward: -0.5 < y* < 0

No obvious modification in forward wrt. backward for prompt D

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Prompt D*

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Prompt D⁰

- Forward: 0 < y* < 0.5, Backward: -0.5 < y* < 0
- Prompt *D* ~ Non-prompt J/ψ

Prompt D*

No obvious modification in forward wrt. backward for prompt D

HF muon flow in p+Pb

Low Multiplicity **High Multiplicity ATLAS** Preliminary $0.5 < p_{\tau}^{h} < 5 \text{ GeV}$ **ATLAS** Preliminary p+Pb p+Pb $\sqrt{s_{\rm NN}}$ =8.16 TeV, 171 nb⁻¹ $\sqrt{s_{\rm NN}}$ =8.16 TeV, 171 nb⁻¹ $4 < p_{\tau}^{\mu} < 4.5 \text{ GeV}$ h- μ Correlations $h-\mu$ Correlations $0 \le N_{\rm ch}^{\rm rec} < 40$ 1.04 1.02 1.02 (V U V U V 0.98 $C(\Delta \eta, \Delta \phi)$ -2 2 ⊲ø 2 ⊲ø

- Event collected by single muon + high multiplicity trigger
- Two particle correlation between HF muon and charged hadrons

HF muon flow in p+Pb

Low Multiplicity **High Multiplicity** $0.5 < p_{\tau}^{h} < 5 \text{ GeV}$ **ATLAS** Preliminary *p*+Pb **ATLAS** Preliminary p+Pb $\sqrt{s_{NN}}$ =8.16 TeV, 171 nb⁻¹ $\sqrt{s_{\rm NN}}$ =8.16 TeV, 171 nb⁻¹ $4 < p_{\pm}^{\mu} < 4.5 \text{ GeV}$ $h-\mu$ Correlations $h-\mu$ Correlations $0 \le N_{\rm ch}^{\rm rec} < 40$ 1.04 1.02 (\$ \$ 0.98 C(Δη,Δφ) -2 d_{ϕ}

- Event collected by muon + high multiplicity trigger
- Two particle correlation between HF muon and charged hadrons
- Non-flow background subtracted with correlation template fit and fake HF muon background suppressed with momentum imbalance cut

HF muon flow in p+Pb

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- v_2 (HF muon) ~ 0.6 × v_2 (hadron)

No obvious multiplicity dependence of HF muon v_2

D* meson flow in p+Pb

- result favors $v_{2,2} > 0$
- $1 \sim 2\sigma$ hint for cos($2\Delta\phi$) azimuthal modulation of D* Improved final results of D meson v_n will be available soon

Template fit performed to background subtracted correlation function,

Summary

- Large system: significant suppression and flow of all heavy flavor probes
- Small system: no net modification on heavy flavor production at mid-rapidity / high p_T , but significant HF muon flow is observed

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System size

Summary

- Large system: significant suppression and flow of all heavy flavor probes
- Small system: no net modification on heavy flavor production at mid-rapidity / high p_T , but significant HF muon flow is observed
- Crucial to have simultaneous theoretical descriptions on HF <u>yield</u> and <u>flow</u> in <u>large</u> system and <u>small</u> system

System size

ATLAS detector

By J. Goodson

HF muons

Momentum imbalance $\Delta p = p_{\text{ID}} - (p_{\text{MS}} + p_{\text{Calo}})$ template fit

ЧN

Muon Spectrometer

HF muon yields in Pb+Pb

Signal fraction

Yields

HF muon v_2 in Pb+Pb

- Good agreement between ATLAS and ALICE
- Smaller uncertainties of ATLAS results would provide tight constraints on models

HF muon in pp vs FONLL

HF muon yields wrt. event plane

HF muon flow in Pb+Pb

v_3

• Measured HF muon v_3 and v_4 agrees DABMod calculations

 v_4

Dreconstruction

Trigger selection

D⁰ selection

D* selection

Two tracks, $p_T > 1$ GeV π and K masses assigned in turn, $1.7 < m(K\pi) < 2.0$ GeV Vertex probability Pointing angle $\cos \alpha_{xy}$ $L_{xy} / \sigma(L_{xy})$

A selected D⁰ vertex An additional track (π mass), same charge with the π in D⁰ with soft pion p_T > 400 MeV (for yield) or 250 MeV (for correlation) 1.75 < m(K π) < 1.96 GeV as SR, m(K π) < 1.76 GeV || m(K π) > 1.96 GeV as CR

MinBias (+HMT for correlation)

Cross sections

- Prompt D^0 (3 < p_T < 30 GeV) and prompt D^* (5 < p_T < 30 GeV)</p>
- ▶ $|y_{lab}(D)| < 1.0$ for better mass resolution $\rightarrow -1.5 < y^* < 0.5$
- FONLL (fixed-order next-leading-logarithm) prediction extrapolated from 7 and 8 TeV calculates, and scaled by 208
- Relatively small modification in p+Pb

- **FONLL uncertainties**
- renormalisation scale
- factorization scale
- charm quark masspdf

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Cross sections

- Data and FONLL are comparable in whole kinematic range
- Relatively small modification in *p*+Pb

Recoil jet bias estimation

Template fits — µ-h in p+Pb

Systematics for mu-h correlation

- Choice of peripheral bin 0-20, 20-40, 10-20, 20-30, 30-40
- Background muons
- **Efficiency correction**
- Track/muon selection
- Pileup
- Acceptance

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Peripheral bin

Background Muons Trigger & Tracking Efficiency

Muon Selections

Pileup

Pair Acceptance

systematics for muon-hadron correlation

D*-hadron correlation

- Event collected by MinBias and high multiplicity triggers
- and $-1.5 < y^* < 0.5$)
- Charged particles $p_T > 0.25$ GeV, $\Delta \eta > 1$ for more statistics for 2PC
- Using sideband region 150 < Δm < 170 MeV to estimation the background correlation function 41

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Third soft pion from D* decay with $p_T > 250$ MeV for larger D* fiducial volume ($3 < p_T < 30$ GeV

D*-h correlation fit

- Assuming weak multiplicity dependence of near-side D*-h long range correlation
- Peripheral reference bin $10 < N_{ch} < 80$
- Simultaneous template fit method applied to low and high N_{ch} single correlation functions

Sideband subtraction

- Systematics:
- Statistical uncertainty in *f*_{sig}
- N_{ch} dependence of f_{sig}
- ∆m dependence of sideband correlation

