Recent results on heavy flavor in small and large systems from ATLAS and CMS

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Why heavy quarks?

• Heavy quarks are produced in initial hard scatterings
  - carry information about all stages of the collision
  - production can be calculated with pQCD ($m_b > m_c > \Lambda_{\text{QCD}}$)

• Probe QGP through energy loss mechanisms
  - collisional + radiative
  - mass hierarchy, flavor dependence.

• Keep identity after hadronization

• Possible probe for strong short-lived EM field
Open heavy flavor
Heavy flavor in p+p

General features of heavy flavor production are more-or-less well understood in p+p, although theory uncertainties are rather large.

Baseline for nucleus-nucleus collisions study
Heavy flavor analysis using DCA

- Charm, beauty and light flavors are separated using Distance of Closest Approach (DCA) distribution unfolding with templates obtained from MC.
- Based on difference of lifetimes for charm and beauty mesons.
Charm and beauty flow in Pb+Pb

Muons from HF decays

Charm: non-zero $v_2$ and $v_3$ up to 20 GeV/c
Beauty: smaller but non-zero $v_2$
First measurement of beauty $v_3$ consistent with zero at all centralities.
Heavy flavor flow in p+Pb

Charm flow in p+Pb (prompt $D^0$) similar to that of hidden flavor (prompt $J/\psi$).

Beauty flow in p+Pb (non-prompt $D^0$):
First measurement: consistent with zero at low $p_T$, consistent with prompt $D^0$ (charm) at high $p_T$.

CGC model reasonably consistent with data.
Theory comparison for Pb+Pb

Good matching of theory to data for DREENA-B (*PLB 791 (2019) 236*). (Dynamic energy loss in 1+1D expanding QCD medium)

Matching of DAB-MOD (*Phys. Rev. C 96, 064903*) worse for the flow from charm. (2D+1 viscous hydrodynamic expansion with event-by-event fluctuations)
Charm and beauty flow in p+p

Muons from HF decays

Charm: non-zero $v_2$, similar to inclusive charged hadrons.

Beauty: $v_2$ consistent with zero.

Collectivity in pp does not persist to heavy b-quarks!
Charm flow in p+p vs. p+Pb

CMS Preliminary

CMS-PAS-HIN-19-009

p+p consistent with p+Pb for similar multiplicities
Jet shape: b-jets shapes in p+p

Jet shape distribution

\[
\rho(\Delta r) = \frac{1}{\delta r} \frac{1}{N_{jets}} \frac{\sum_{jets} \sum_{trk \in (\Delta r_a, \Delta r_b)} p_{T}^{trk}}{\sum_{jets} \sum_{trk} p_{T}^{trk}}
\]

B-jets have different shape with respect to inclusive jets

Poorly reproduced in PYTHIA

⇒ Flavor dependence in parton fragmentation
Jet shape: $D^0$ in jets in $p+p$ and $Pb+Pb$

Radial profile of $D^0$ mesons in jets:

Hint of wider distribution in Pb+Pb than p+p at low $p_T$

⇒ Charm quark diffusion with respect to the jet axis

Energy loss CCNU model includes both elastic and inelastic collisions of all flavors


arXiv:1911.01461
D⁰ flow in Pb+Pb: search for strong EM effects

CMS-PAS-HIN-19-008

Theory \( (e.g. \) Phys. Rev. C 98 (2018) 055201) predicts creation of strong \( (10^{16} \text{T}) \) and transient \( (10^{-1} \text{ fm}/c) \) EM fields in HI collisions.

Coulomb electric field will cause charge-dependent splitting of \( v_2 \) and \( <p_T> \)

Heavy flavor, created early in the collision has more chances to be affected before hadronization.

Compare \( v_2 \) for prompt \( D^0 \) (\( \bar{u}c \)) and \( \bar{D}^0 \) (\( u\bar{c} \))

Mutli-differential analysis vs. \( |y|, p_T, \) centrality

Consistent with no difference
Quarkonia
Upsilon suppression in Pb+Pb

Expected order of suppression, larger suppression in central collisions.
Theory comparison

- Both models include color screening and feed-down, Du,Rapp,He includes regeneration
Upsilon suppression in more details

ATLAS-CONF-2019-054

Prompt $J/\psi$ (charm) is consistent with $Y(1S)$ despite different binding energy

$\Rightarrow$ different regeneration?

Non-prompt $J/\psi$ (beauty) less suppressed than prompt, but still consistent with $Y(1S)$.

$\Rightarrow$ many competing mechanisms?

No $p_T$ or rapidity dependence for suppression
Upsilon flow in Pb+Pb

First measurement
Consistent with no flow, in contrast with open beauty

non-prompt J/ψ

muons from beauty
Conclusions

• General features of heavy flavor production in p+p collisions are reasonably well understood theoretically and can serve as a baseline for HI studies.

• In HI collisions both charm and beauty flow, but beauty $v_3$ is zero.

• In high multiplicity $p+p$ collisions open charm flow is similar to light flavors, but no beauty flow.

• Charm flow in $p+p$ is consistent with that in $p+Pb$ at the same multiplicity.

• B-jets are broader, $D^0$ have wider distribution in jets compared to light flavor. ⇒ flavor dependence of parton fragmentation.

• Upsilon suppression in Pb+Pb exhibits expected order, well described by theory.

• Comparison to $J/\psi$ indicates importance of regeneration, many competing processes