Open and Hidden Heavy-flavor Production and Flow

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On behalf of LHCb presenting results from ALICE, ATLAS, CMS and LHCb

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QGP medium needs to have a large volume: heavy ion collisions

Probe needs to be formed and not shower in the vacuum before QGP formation: $\tau_{\text{HF\_FORM}} < 0.07 \text{ fm}$, $\tau_{\text{QGP}} \sim 0.6 \text{ fm}$

Needs different quark mass scales: charm and bottom quarks

Probe from $p_T < m_Q$ to $p_T >> m_Q$
Analogy with Medical Tomography

MEDICAL TOMOGRAPHY

- Good control, well know source
- Medium to probe (patient) is still
- Patient is the same for many events

QGP TOMOGRAPHY

- Good control, well know source?
- Medium to probe expands almost at the speed of light
- Medium geometry change every event

ATLAS

JHEP11(2013)183
QGP Tomography

Source intensity (cross section) measured in p+p collisions.

Needs to understand how the source is affected by the nucleus immediately after the collision (initial state effects). Studied in small systems (p+A)

QGP tomography done in A+A collisions. Measurements are

- nuclear modification factor
  \[ R_{AA} = \frac{\text{yield in A+A}}{N_{\text{coll}}(\text{yield in p+p})} \]

- Fourier expansion of particle azimuthal asymmetries
  \[ \frac{dN}{d\phi} \propto 1 + 2 \sum_{n=1}^{\text{inf}} v_n \cos n (\phi - \Phi_{RP}) \] (event plane meth.)
Initial State studies in small systems.
Beauty hadron in pPb collisions at $\sqrt{s_{NN}} = 8.16$ TeV

Consistency with nPDFs at large $Q^2$, where uncertainties are smaller.

LHCb-CONF-2018-004
Ratio larger than found in $e^+e^-$ and ep collisions.

Ratio at mid-rapidity larger than forward rapidity.

Small room for charm coalescence in pPb.
Baryon/meson ratio doesn't change from pp at forward rapidity.

Large fluctuation at backward rapidity
D$^0$ in pHe and pAr fixed target

One of the first fixed target results from LHCb

Phys. Rev. Lett. 122, 132002

No evidence for strong charm enhancement predicted by intrinsic charm estimation.

More data will allow a better exploration of $x_2$. 
Probing QGP in heavy ion collisions.
TAMU: transport model
DABMod: energy loss model

$p_T$ region mostly dominated by bottom quark contributions.
Semi-leptonic decays of beauty

Using electron impact parameter selection.

Room for smaller suppression of b-quarks.

B-meson $p_T$ should be unfold from electron $p_T$ for a direct comparison.
Another B-meson decay channel observed by CMS

Smaller suppression of non-prompt $D^0$ suggesting the quark mass dependency of the energy loss in QGP

$p_T$ of the original B-meson needs to be unfold from non-prompt $D^0$ and J/ψ
D-meson tagged jets $R_{AA}$ consistent with inclusive D-mesons.

Radial profile of D-mesons around the jet axis can be modified in PbPb collisions. Modification is not observed for higher D-meson $p_T$. 
• ALICE results consistent with charm hadron coalescence (hadrons produced inside the QGP medium).

• No coalescence seen by CMS at larger $p_T$. CMS includes both $\Lambda_C$ and $D^0$ anti-particles.
$\Lambda_c$ in PbPb

CMS Preliminary

$\Lambda_c^+ + \Lambda_c^-$

PbPb 44/102 $\mu$b$^{-1}$, pp 38 nb$^{-1}$ (5.02 TeV)

$\langle N_{\text{part}} \rangle$

Cent. 0-100%

Cent. 30-100%

Cent. 0-30%

$\Lambda_c^+, \mid y \mid < 0.5, 0-80\%$ Pb-Pb Pb-Pb, $\sqrt{s_{NN}} = 5.02$ TeV

Catania

frag. + coal. in Pb-Pb, fragm. in pp
coal. in Pb-Pb, fragm. + coal. in pp

$\Lambda_c^+, \mid y \mid < 0.5, 0-80\%$ Pb-Pb, $\sqrt{s_{NN}} = 5.02$ TeV
Recombination of $B$-mesons?

CMS

- $B^0_s$
- $B^+$
- TAMU
- CUJET3.0

Recombination included in TAMU


CUJET [JHEP 02 (2016) 169]: collisional and radiative energy loss.

Similar behavior observed for $D_s$ by ALICE [JHEP 1810 (2018) 174].

arXiv:1810.03022
Heavy Flavor Flow Harmonics.

\[ v_n = \langle \cos(n(\phi - \Psi_n)) \rangle \]

Models are still unable to describe HF suppression and flow simultaneously.
Event Shape Engineering with D-mesons

Positive correlation between D-meson and light hadron flow.

Yields indicate no differences with eccentricity in the current uncertainties.

\[ \langle v_2 \rangle_{\text{small} - q_2} < \langle v_2 \rangle_{\text{unb}} \]

\[ \langle v_2 \rangle_{\text{large} - q_2} > \langle v_2 \rangle_{\text{unb}} \]
Sensibility to Initial Magnet Field Effects

Charge asymmetry of direct flow $v_1$ is a signature for the initial magnetic field in the collision.

Effect depends on the quark mass and formation time, charm should be more sensitive than light quarks.
QUARKONIA
Just look at who breaks in the medium or not.
New result from ATLAS confirming previous observations from ALICE, CMS and LHCb.
Relative nuclear modification of $\Upsilon(2S)$, $\Upsilon(3S)$ over $\Upsilon(1S)$.

Data well described by the latest calculations on the bottomonia breaking in comoving particles. NO QGP involved.
Charmonia Breaking in PbPb

\[ \Psi(2S) \] additional breaking in a \( p_T \) region where coalescence may not be important.

Confirm previous results from ALICE and CMS.
New set of $\Upsilon$ $R_{AA}$ at 5 TeV showing no changes from 2.76 TeV.
New result from ATLAS covering high-\(p_T\) J/ψ.

Flow attributed to charmonium coalescence/recombination.
Bottomonia should not be produced by coalescence because of the small number of b-bbar in the environment.

Indeed, that is what is observed.
But how coalescence can exist in small systems?

Same model describing $J/\psi R_{pA}$ using transport in medium cannot describe $v_2$.

Challenge for hydro descriptions.

**J/$\psi$ elliptic flow in pPb collisions**

Jet contribution subtracted

CMS: PLB 791 (2019) 172

ALICE: PLB 780 (2018) 7

arXiv:1808.10014v2

In-Medium Charmonium Production in pPb Collisions
$W(\cos\theta, \phi) \propto \frac{1}{3 + \lambda_\theta} \cdot (1 + \lambda_\theta \cos^2 \theta + \lambda_\phi \sin^2 \theta \cos 2\phi + \lambda_{\theta\phi} \sin 2\theta \cos \phi)$

All polarization parameters are consistent with zero in all frames.

More statistics in peripheral events may be more sensitive to QGP vortices as seen by STAR with Lambdas.

ALI-DER-314900
LHCb Entering in the Game of Large Systems

**SMOG: FIXED TARGET**

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**COLLIDER MODE**

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D-meson

$J/\psi$

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5/22/2019
SUMMARY of the SUMMARY

- Data in pPb collisions is more precise than the nuclear PDFs
- Open heavy flavor regeneration is not seen yet
- No intrinsic charm observed in fixed target mode
- More observations of stronger suppression of excited quarkonia states

- Indications of a small mass ordering for the quark energy loss in QGP, needs more data for a more assertive statement
- Large regeneration of charm hadrons and perhaps in bottom hadrons
- Exciting new measurement of direct flow of D-mesons indicating a sensitive probe for initial magnet fields
- More observations of J/ψ flow attributed to charmonium coalescence
- γ shows no azimuthal asymmetry confirming that bottomonium coalescence is small
- Surprising azimuthal asymmetry of J/ψ in pPb, but coalescence cannot be produced in such small systems

- LHC is exploring new observables:
  - D-meson tagged jets
  - Quarkonia polarization in PbPb
  - Measurements in fixed target

Muchas Gracias
BACKUP SLIDES
Understanding the source in p+p collisions
Heavy Quark Formation

arXiv:1810.11102v1

CMS

$27.4 \text{ pb}^{-1} (5.02 \text{ TeV pp}) + 530 \mu\text{b}^{-1} (5.02 \text{ TeV PbPb})$

$\frac{D^0 + \bar{D}^0}{2}$ from $b$ hadrons

$|y| < 1$

Global uncertainty

- pp data: 2.5%
- PbPb data: +4.1%, -3.6%

FONLL

Data / FONLL

FONLL uncertainty

$D^0 p_T$ (GeV/c)

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Results consistent with no nuclear modification of $\Lambda_c$ and D-mesons.