Heavy Flavor Workshop Report

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2024 RHIC/AGS Annual User’s Meeting
June 11-14, 2024
Heavy Flavor Workshop
June 12, 2024

There were 9 presentations on open heavy flavor and heavy quarkonia.

• Open Heavy Flavor Physics - STAR, Ondrej Lomicky
• Open Heavy Flavor physics - PHENIX, Daniel Richford
• Open Heavy Flavor Physics - sPHENIX, Thomas Marshall
• Open Heavy Flavor Physics - (LHC) Preeti Dhankher
• Heavy Flavor Jets - sPHENIX, Jakub Kvapil
• HF Quarkonium Physics - STAR, Wei Zhang
• HF Quarkonium Physics - PHENIX, Ming Liu
• HF Quarkonium Physics - sPHENIX, Marzia Rosati
• HF Quarkonium Physics - (LHC) Minjung Kim
Introduction

A comprehensive summary of the large number of interesting results presented in the workshop is impossible here.

I will present selected highlights only - organized by topic.

Please see the original talk slides for details, and for proper referencing of sources.

https://indico.bnl.gov/event/22687/
Open Heavy Flavor

Can be studied by measuring yields of:

• HF decay leptons
• Reconstructed hadronic decays of HF mesons
• Heavy flavor tagged jets

Good progress on all three fronts.
Separation of charm and bottom energy loss clear. STAR & PHENIX agreement within uncertainties.
HF electrons at LHC - b/c separation

Interaction of heavy quarks with the QGP

Dead cone effect: gluon radiation suppressed at angles smaller than $\theta < m/E$

Consistent with mass dependent hierarchy!!

RAA(q/g) < RAA(c) < RAA(b)

Probe modified by the medium!!

$R_{AA} = \frac{dN_{AA}/dp_T}{< T_{AA} > d\sigma_{pp}/dp_T}$

“Flow bump” due to (radial) flow of medium and coupling at small $p_T$
HF electron $v_2$ at RHIC

Daniel Richford

Good agreement between PHENIX and STAR.
Similar $v_2$ at mid and forward rapidity in PHENIX.

Ondrej Lomicky
Open HF hadrons

**PRELIMINARY**

Adding data from Zr+Zr and Ru+Ru collisions

- No obvious centrality dependence for the low $p_T$ suppression
  - Interplay of radial flow, the cold nuclear matter effects, and the charm hadrochemistry
- Suppression in central collisions at $p_T > 3$ GeV/c
  - Significant energy loss of c quarks in the bulk QCD medium
  - Centrality dependence of the high $p_T$ suppression
- Good description by a Langevin model from 3 GeV/c
- Similar suppression in isobar and Au+Au collisions despite different $\langle N_{\text{part}} \rangle$ at a given energy

Constraining nPDFs

LHCb $D^0$ data places **very** stringent bounds on the gluon nPDF.

- Important step in constraining models of HF modification in nuclear targets!
To come: open HF in sPHENIX

Thomas Marshall
Jets

Jet probe a wide range of $Q^2$

Hadronic Collision

Hard Parton

High energy parton (quark or gluon)

Parton shower

Hadronization/Confinement

Hadrons

High energy

Low energy
D0 jet fragmentation function in Au+Au @ 200 GeV

\[ z_{Jet} = \frac{p_{T,Jet} \cdot p_{T,D^0}}{|p_{T,Jet}|^2} \]

- \( z_{Jet} \) related to fragmentation function in DGLAP equation
- Hard fragmented D0-jet yield suppressed in central/midcentral events
- Soft fragmented D0-jet yield ratio consistent with 1 in central/midcentral events
- LIDO agrees well with yield in peripheral events, slightly underpredicts yield in central events

LIDO, Phys. Rev. C 98, 064901
$D^0$ jets - ALICE

$D^0$ tagged jets compared with inclusive jets.

- Shows clearly the flavor dependence of jet energy loss.

Preeti Dhankher
First direct observation of dead-cone effect

The graph shows the ratio of the splitting angle ($\theta$) distribution for $D^0$-tagged vs. inclusive jets, vs. $E_{\text{Radiator}}$. The equation for the ratio is given as:

$$R(\theta) = \frac{1}{N^{D^0\text{jets}}} \frac{dN^{D^0\text{jets}}}{d\ln(1/\theta)} / \frac{1}{N^{\text{inclusive jets}}} \frac{dN^{\text{inclusive jets}}}{d\ln(1/\theta)}$$

This ratio indicates significant suppression of small-angle emissions.
To come: HF tagged jets in sPHENIX

Particle flow

- Almost half of the jet energy is carried by the neutral particles
  - The importance to study full jets
  - sPHENIX has the first mid-rapidity HCAL at RHIC!
- Initial implementation of particle flow at sPHENIX to connect charged tracks and calorimeter information
Hadronization of charm and bottom hadrons

HF baryon/meson ratio enhancement

- The $\Lambda_c/D^0$ ratio is enhanced at low $p_T$ even in pp collisions.
- The $\Lambda_b/B^0$ ratio is multiplicity dependent in pp collisions.

Described by color reconnection, quark-coalescence and statistical hadronization models.

Preei Dhankher

PbPb

pp

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Energy dependence of $J/\psi$ modification

The energy dependence is a mix of strongly energy dependent effects:

- Gluon nPDFs
- Nuclear absorption (collisions with nucleons)
- Hot matter effects
- charm coalescence at hadronization (huge charm production at LHC)
ψ(2S) / J/ψ ratio in small(er) systems

New measurements by STAR in intermediate mass systems show strong differential suppression of the ψ(2S) relative to the J/ψ.

Ming Liu

Wei Zhang
ψ(2S) in Pb-Pb at LHC

ψ(2S) behavior at LHC energies mirrors J/ψ behavior in PbPb.

• ψ(2S) regeneration at low p_T.
• Well described by transport model.

MInjung Kim
Bottomonium at RHIC

STAR measurements of $Y(1S)$ and $Y(2S)$

- Extended to Zr+Zr and Ru+Ru collisions at 200 GeV collision energy.
Bottomonium at LHC

Beautiful $R_{AA}$ data from all experiments.

Ongoing campaign to increase precision for Y(2S) and Y(3S).
J/ψ event multiplicity at RHIC

J/ψ Yields vs Event Multiplicity: All Together

RED  = Tracklets $N_{ch}^{N}(1.2 < \eta < 2.4)$
      [inclusive, dimuon subtracted]
Green = J/ψ (1.2 < $y$ < 2.2)
Blue  = J/ψ (-2.2 < $y$ < -1.2)

J/ψ $\rightarrow \mu^+ + \mu^-$

- Less MPI contribution to the forward J/ψ production?
J/ψ event multiplicity at RHIC

PYTHIA vs Data: Multi-Parton-Interactions

- PYTHIA8 Detroit tune reasonably agree with PHENIX data, with MPI
  - w/o MPI, fit failed badly
- Proper understanding of the Underline Events is important
Bottomonium production vs. event activity

- $\Upsilon(2S)/\Upsilon(1S)$ and $\Upsilon(3S)/\Upsilon(1S)$ decreases with multiplicity in pp as well as in p-Pb collisions.
- Decreasing trend with multiplicity seen for all azimuthal angles at high $p_T$.
  → Connection to underlying event (UE)
To come: sPHENIX Bottomonium

Mass resolution of $\sim 100$ MeV/$c^2$ enables the separation of all three Upsilon states.

Anticipated performance (assumes $Y(3S)$ suppression similar to LHC energy):

Marzia Rosati