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Recent Developments in Open Heavy Flavor Experiments

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Abstract

Heavy quark program has been one of the focused programs at RHIC and LHC to study detail properties of strongly-coupled Quark-Gluon Plasma (sQGP). I will review recent experimental achievements on open heavy flavor production in heavy ion collisions, including measurements of nuclear modification factors, elliptic flow and heavy quark triggered correlations. By comparing with most sophisticated theoretical models, I will comment on physics implications on current understanding of sQGP medium properties. In the end, I will discuss future plans of utilizing heavy flavor quarks to probe emergent QCD properties in heavy ion collisions at both RHIC and LHC.

Keywords: open heavy flavor, heavy quark diffusion, nuclear modification factor, elliptic flow, silicon pixel detector

Heavy quarks, due to their intrinsic large masses, offer unique information for the study of hot and dense strongly-coupled Quark-Gluon Plasma (sQGP) matter. The main focus of measuring heavy quark production in heavy ion collisions is to understand the flavor/mass dependence of parton energy loss and to quantify medium transport properties utilizing the enhanced sensitivity of heavy mass quarks. Heavy mass particles propagating through a thermalized medium can be treated in analogy to the "Brownian" motion in molecular physics applied in the QCD matter. The drag and diffusion of heavy quarks can be usually characterized by the heavy quark spacial diffusion coefficient $\mathbf{D}_{\mathrm{HQ}}$, one of the intrinsic transport properties of the medium. The key questions we would like to address are a) how do heavy quarks lose their energy in the sQGP medium; b) do heavy quarks flow with the medium; and c) what are the medium transport properties, e.g. $\mathbf{D}_{\mathrm{HQ}}$ etc. This proceedings will be focusing on what we have learned about the hot sQGP medium using heavy quark production, while there are certainly some important ingredients, such as the cold nuclear effect one need to pay attention to.

Over the past decade, we have been pursing measurements of heavy quark production in relativistic heavy ion collisions since RHIC and LHC. The early measurements at RHIC experiments were mostly carried out using semi-leptonic decay channels. The precision of these measurements is limited by the relative large systematic uncertainties involved in the electron analysis, the complicated interpretation due to the mixture of charm and bottom decays as well as the kinematic smearing due to decays. The ultimate way to improve the measurements of heavy quark production is to topologically reconstruct heavy flavor hardon decay vertices. However, measuring heavy flavor hadrons is more challenging than other light flavor hadrons due to their short lifetimes ($c\tau \sim$ 50-500 μm). Silicon pixel detectors are crucial in order to reduce huge combinatorial background in high multiplicity heavy ion collisions.

Table 1 lists silicon pixel subsystems used in major heavy ion experiments at RHIC and LHC. ATLAS, CMS, ALICE and PHENIX collaboration use the hybrid sensor technology which has a typical pixel size of a couple of hundred microns and $1\%X_0$ (radiation length) thickness. The STAR experiment recently installed a new pixel detector based on the Monotholic Active Pixel Sensor (MAPS) technology. The sensor has a pixel size of $20{\times}20$ $\mu\mathrm{m}^2$ and a very thin thickness of $0.4\%X_0$ for the first layer. The STAR pixel detec-

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Table 1: Silicon pixel detectors currently in major heavy ion experiments

	ATLAS	CMS	ALICE	PHENIX	STAR
Sensor tech.	Hybrid	Hybrid	Hybrid	Hybrid	MAPS
Pixel size (μm^2)	50×400	100×150	50×425	50×425	20×20
Radius of first layer (cm)	5.1	4.4	3.9	2.5	2.8
Thickness of first layer (X_0)	1%	1%	1%	1%	0.4%

tor is designed to precisely measure the charmed hadron production in the hydrodynamic region where they are particularly sensitive to the heavy quark diffusion coefficient $\mathbf{D}_{\mathrm{HQ}}$ in the sQGP. The results discussed here haven't included those from RHIC pixel detectors yet. These tools will enable us to start the precision measurements of heavy quark production in heavy ion collisions.

Charm production in $p+p$ collisions is expected to be calculable in perturbative QCD due to the large scale set by the charm quark mass. Figure 1 shows measurements of total $c\bar{c}$ pair production p_{T} differential cross sections at mid-rapidity in $p + p(\bar{p})$ collisions from $\sqrt{s}$ = 200 GeV up to 7 TeV [1, 2, 3]. FONLL pQCD calculations shown as shaded bands are consistent with experimental data in all these energies. The data precision is so significant that it can provide better constraints on the parameters used in the pQCD calculation of charm production. Recent theoretical works have shown a better understanding of perturbative QCD calculation in heavy quark production [4]. There are also recent measurements on bottom hadron production using the exclusive reconstruction channel and the data show also a good agreement with pQCD calculations [5].

Charm quarks are expected to be dominantly produced through initial hard scatterings given that the typical temperature of sQGP media at RHIC and LHC is still significantly smaller than the charm quark mass. At RHIC, this has been verified with the charm total cross section measurements from $p + p$ collisions to central Au+Au collisions. The measurement shows the charm total cross section at mid-rapidity scales with number-of-binary-collision (N_{bin}) scaling [6]. At LHC energy, this will need to wait for the ALICE tracking upgrade program to enable measurements at low momentum region for total cross section determination. In the meantime, one would need to measure different charm hadron states in order to further constrain our understanding of total charm production. The total charm production cross section is crucial for the interpretation of both open charm as well as charmonium production in heavy ion collisions.

Although the total charm cross section follows the

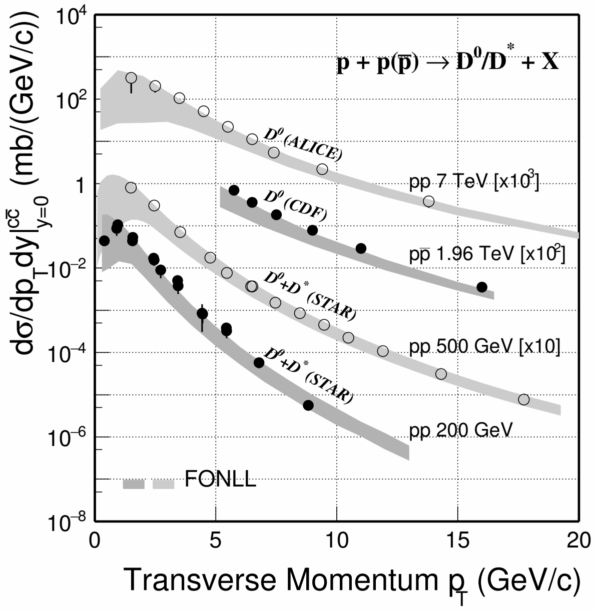

Figure 1: Total charm quark pair production cross section at mid-rapidity via measurements of D-mesons in $p + p(\bar{p})$ collisions from $\sqrt{s_{\mathrm{NN}}}$ = 200 - 7000 GeV [1, 2, 3]. The measurements are compared to pQCD FONLL calculations shown as shaded bands.

N_{bin} scaling, the charm hadron p_{T} spectrum is significantly modified in central Au+Au collisions. Figure 2 shows a recent measurement of D-meson R_{AA} as a function of p_{T} in 0-10% central Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV by the STAR experiment [6]. The measurement were done with a dataset taken before the pixel detector that was installed. The data show a significant suppression at high p_{T} for D-mesons which indicates strong charm quarks lose significant energy in the sQGP medium. In the low to intermediate p_{T}, the data show a bump structure which is reproduced by models that include coalescence of flowing light and charm quarks. The Torino model shown here doesn't include the coalescence scheme which fails to describe the feature in data. While recently the new development in this model including the coalescence mechanism suggests a simi-