11th international workshop on High-pT Physics in the RHIC & LHC Era

Tuesday 12 April 2016 - Friday 15 April 2016

BNL Physics Building

Book of Abstracts

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Session 1 / **23**

Elimination of pQCD renormalization scale ambiguities for collider reactions

Author: Stanley Brodsky[1]

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A primary problem for perturbative QCD analyses is how to set the renormalization scale of the QCD running coupling in order to achieve maximally precise fixed-order predictions for physical observables. The Principle of Maximum Conformality (PMC) eliminates the ambiguities associated with the conventional renormalization scale-setting procedure, giving predictions which are independent of the choice of the renormalization scheme. The scales of the QCD couplings and the effective number of quark flavors are set order-by-order in the pQCD series.

The PMC has a rigorous theoretical foundation, satisfying renormalization group invariance and all of the self-consistency conditions derived from the renormalization group. The PMC scales at each order are obtained by shifting the arguments of α_s to eliminate all non-conformal $\{\beta_i\}$-terms in the pQCD series. The $\{\beta_i\}$ terms are determined from renormalization group equations without ambiguity. One then obtains the correct scale of the running coupling at each order and at each phase-space point. The PMC reduces in the $N_C \to 0$ Abelian limit to the Gell-Mann-Low method.

In this talk, I will summarize recent PMC applications for a number of collider processes. If one applies the PMC to compute the top-quark pair forward-backward asymmetry at the next-to-next-to-leading order level, one obtains a comprehensive, self-consistent pQCD explanation for the Tevatron measurements of the asymmetry, accounting for the "increasing-decreasing" behavior observed by D0 collaboration as the $t\bar{t}$ invariant mass is increased. In the case of hadronic Z decay, one can achieve precise scheme-independent predictions for the decay widths at each order without scale ambiguities by applying the PMC.

The application of the PMC systematically eliminates a major theoretical uncertainty for pQCD predictions, thus increasing the sensitivity of the colliders to possible new physics beyond the Standard Model.

Session 1 / **19**

Overview of inclusive light hadron and jet suppression observables at RHIC and the LHC

Author: Ivan Vitev[1]

[1] *Los Alamos National Laboratory*

In the framework of soft-collinear effective theory with Glauber gluons, results and predictions for inclusive hadron suppression, based upon in-medium parton shower evolution, are presented for Au+Au and Pb+Pb collisions at RHIC and LHC energies, respectively. The SCETG medium-induced splitting kernels are further implemented to evaluate the attenuation of reconstructed jet cross in such reactions and to examine their centrality and radius R dependence. Building upon a previously developed method to systematically resum the jet shape at next-to-leading logarithmic accuracy, a quantitative understanding of the jet shape modification measurement in Pb+Pb collisions at LHC can be achieved. Predictions for photon-tagged jet cross sections and shapes, that can shed light on the parton flavor dependence of in-medium parton shower modification, are also given.

Session 1 / **24**

Quenching of heavy flavors at high pT

Author: Boris Kopeliovich[1]

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Vacuum radiation of high-pT heavy quarks ceases at a short time scale, as is confirmed by LEP measurements of the fragmentation functions of heavy flavors. Production of a heavy flavored hadron is considerably delayed in a dense medium , what causes a strong suppression of the heavy quark yield in AA collisions in good accord with data.

Session 2 / **31**

Quarkonia at LHC

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TBA

Session 2 / **7**

Quarkonium production in proton-proton and proton-lead collisions with ATLAS at the LHC

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The suppression of heavy quarkonium states such as J/psi, psi(2S) and Upsilon(nS) in heavy-ion collisions, with respect to proton-proton collisions, plays an important role in studying the hot and dense medium formed in the larger collision systems. A full assessment of this suppression requires understanding of nuclear effects which may affect the production of quarkonium states even in the absence of the medium. The study of quarkonium production in proton-nucleus collisions serves as a baseline for understanding heavy-ion collisions and furthers our knowledge of such nuclear effects. Using proton-lead and proton-proton collision data collected at the LHC in 2013, the ATLAS experiment measures J/psi, psi(2S) and Upsilon(nS) production. The yields of charmonium states are separated into contributions from b-hadron decays and prompt production. The nuclear modification factors and excited-to-ground state ratios are presented. All quarkonium states are reconstructed via the dimuon decay channel and the yields are shown differentially in intervals of transverse momentum, rapidity and event activity.

Session 2 / **17**

J/ψ and Υ measurements via di-lepton decay channels with the STAR experiment

Author: Rosi Reed[1]

[1] *Lehigh University*

Suppression of quarkonia in heavy-ion collisions due to the Debye screening of the potential between the heavy quarks was one of the first hypothesized signatures of the Quark Gluon Plasma (QGP). However, other effects besides Debye screening, such as the statistical recombination of heavy quark anti-quark pairs, or co-mover absorption, can also affect quarkonium production in heavy-ion collisions. The STAR experiment has made many successful measurements of the J/ψ and Υ families via the di-electron channel in p+p, d+Au, Au+Au and U+U collisions, which provide constraints for models of quarkonium production in these various systems. These constraints are necessary to fully understand the influence of the different physics processes on the quarkonium yields. The Muon Telescope Detector (MTD), designed to both trigger on and identify muons based on precise timing information, was fully installed in STAR in 2014. This allows quarkonia measurements via the di-muon channel. In particular, it allows a potential separation of the different Υ states, as muons are much less affected by bremsstrahlung than electrons. In this talk, we present an overview of the measurements of J/ψ and Υ mesons measured by the STAR experiment in both di-electron and di-muon channels. We will highlight the recent measurements of J/ψ suppression and elliptic flow at mid-rapidity in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV down to low transverse momenta. Additionally we will show an outlook towards measuring the Υ in the di-muon channel. We will also present measurements of Υ suppression from both Au+Au and U+U collisions.

Session 3 / **26**

High-p_T pion associated with dilepton and heavy quarkonia production in pp collisions at RHIC and LHC

Author: Michal Sumbera[1]

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Different phenomenological models based on saturation physics are used to estimate the Drell-Yan (\gamma and Z_0) dilepton spectra in pp collisions at RHIC and LHC energies in the color dipole formalism. We extend this analysis to heavy quarkonia (such as J/\psi, \Upsilon and \chi_{c,b}) production in the color singlet model. In order to further constrain QCD dynamics we suggest to measure the azimuthal correlation function C(\Delta \phi) between mid-rapidity dilepton pairs (from Drell-Yan process or quarkonia decay) and central or forward high-p_T pions. Predictions for the rapidity and transverse momentum distributions of dileptons and pions are presented.

Authors: Victor Goncalves (Lund univ.), Jan Nemchik (Czech Technical univ.), Roman Pasechnik (Lund univ.), Michal Sumbera (Nuclear Physics Inst. ASCR, speaker)

Session 3 / **40**

Rigorous measurements of jet quenching at RHIC and LHC

Author: Peter Jacobs[1]

[1] *Lawrence Berkeley National Laboratory*

Jets are fundamental objects in QCD. Inclusive jet production is well-understood in elementary collisions, with excellent agreement between pQCD calculations and experiment for jet energies from a few GeV to beyond 1 TeV. This extraordinary accomplishment required decades of development in experimental technique, theory, and IRC-safe reconstruction algorithms to connect the two. Measurements and calculations of quenched jets in heavy ion collisions are yet more challenging, for reasons familiar to us all. However, jet quenching is of interest precisely because of its promise to provide highly controlled probes of the QGP. Meeting this promise likewise requires quenched jet measurements that are “IRC-safe”; specifically, that integrate out hadronic degrees of freedom

and explore the dynamics of quenching in terms of energy flow, thereby measuring quenching at the partonic level. This requirement, for the full kinematic range at RHIC and LHC, imposes strong constraints on quenched jet measurement observables and techniques. I will discuss recent progress towards such rigorous measurements of jet quenching, using data from STAR at RHIC and ALICE at the LHC.

Session 3 / **22**

CMS results on jet quenching studies with high pT jets and heavy flavor mesons

Author: Yen-Jie Lee[1]

[1] *Massachusetts Institute of Technology*

LHC has delivered pp, pPb and PbPb collisions at 2.76 and 5.02 TeV in 2010-15. With the high performance and flexible trigger system and the high resolution inner tracker, CMS has recorded and analyzed large data samples of high pT photons, jets and heavy flavor mesons.

In this talk, recent results of the jet, charged hadron, and heavy flavor meson measurements, covering a wide pseudorapidity and transverse momentum range, are summarized. With the large kinematics range investigated, those results provide important insights to the parton flavor dependence of the energy loss and medium response to the incident high pT parton.

Session 4 / **35**

Jet Physics in ALICE

Author: Joern Putschke[1]

[1] *Wayne State University*

An overview of current jet measurements in pp, pPb and PbPb from the ALICE collaboration will presented and discussed.

Session 4 / **9**

“High-pT” measurements in the RHIC Beam Energy Scan

Author: Stephen Horvat[1]

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The richness of the RHIC program and the capabilities of the PHENIX and STAR detectors enable the study of high-pT energy-loss as a function of centrality, momentum, and particle species. Signatures of energy-loss for high-pT particles in central heavy-ion collisions at the LHC and at top RHIC energies provide evidence for the formation of a QGP. The apparent turnoff of these signatures as the collision energy is reduced in the RHIC Beam Energy Scan would support the conclusion that a QGP is formed at top RHIC and LHC energies. Beyond this, the program facilitates the mapping of the QCD phase diagram and provides an extra dimension for constraining models and disentangling the collection of phenomena that effect particle yields and momenta. These phenomena include impact

parameter dependent nuclear shadowing, radial flow, Cronin-like enhancement, baryon enhancement, hadronic energy-loss, and the primary target of study - partonic energy-loss.

Session 5 / **16**

Jet fragmentation functions in proton and heavy ion collisions

Author: Felix Ringer[1]

[1] *Los Alamos National Laboratory*

The jet fragmentation function describes the longitudinal momentum distribution of hadrons inside a reconstructed jet. We study the jet fragmentation function in proton-proton collisions in the framework of soft-collinear effective theory (SCET). We find that, up to power corrections, the jet fragmentation function can be expressed as the ratio of the fragmenting jet function and the unmeasured jet function. We use our theoretical formalism to describe the jet fragmentation functions for light hadron and heavy meson production measured at the Large Hadron Collider (LHC). Our calculations agree very well with the experimental data for the light hadron production. On the other hand, although our calculations for the heavy meson production inside jets are consistent with the PYTHIA simulation, they fail to describe the LHC data. We find that the jet fragmentation function for heavy meson production is very sensitive to the gluon-to-heavy-meson fragmentation function. In addition, we present calculations for the jet fragmentation function measured in heavy ion collisions. We consider the nuclear modification factor RAA in order to study the properties of the quark-gluon plasma which is produced in heavy ion collisions.

Session 5 / **44**

Jet Mass: a new parameter to study modification of hard jets

Author: Abhijit Majumder[1]

[1] *Wayne State University*

We propose an extension to classify jet modification in heavy-ion collisions by including the jet mass along with its energy. The mass of a jet, as measured by jet reconstruction algorithms, is constrained by the jet's virtuality, which in turn has a considerable effect on such observables as the fragmentation function and jet shape observables. The leading parton, propagating through a dense medium, experiences substantial virtuality (or mass) depletion along with energy loss. Meaningful comparisons between surviving jets and jets produced in p-p collisions require mass depletion to be taken into account. Using a vacuum event generator, we show the close relationship between the actual jet mass and that after applying a jet reconstruction algorithm. Using an in-medium event generator, we demonstrate the clear difference between the mass of a surviving parton exiting a dense medium and a parton with a similar energy formed in a hard scattering event. Effects of this difference on jet observables are discussed.

Session 5 / **39**

Precision theory and Jet mass distributions

Author: Yang-Ting Chien[1]

[1] *Los Alamos National Laboratory*

Jet substructure modifications in heavy ion collisions contain useful information about the quark-gluon plasma. The precise understanding of jet substructures therefore becomes the key to extracting the medium properties. I will discuss the advantage of using effective field theory techniques to systematically perform precise jet substructure calculations. While jet shapes and jet fragmentation functions are covered in this workshop, I will focus on discussing a qualitatively different observable, the jet mass. It is sensitive to soft radiation which allows us to probe the physics at the medium scale in more details. I will explain the factorization and resummation framework, and the challenge in performing precise calculation of jet mass in heavy ion collisions.

Session 5 / **29**

A Hadronization Model for Jets Based on Quark Recombination

Author: Rainer Fries[1]

[1] *Texas A and M University*

Within the JET collaboration we have explored hadronization of jet showers in the vacuum and in nuclear matter based on the idea of quark recombination. We find that partons in the low-z bulk of typical vacuum jet showers usually find recombination partners, while high-z partons are typically too far removed in phase space and need to stay connected to other partons via QCD strings. We model stable hadrons and their resonances through harmonic oscillator wave functions whose parameters have been fit to experimental data. Our model compares well to pure string fragmentation models of hadronization for vacuum jets. The advantage of a recombination based model is that it easily generalizes to jets in a nuclear medium. In this talk we discuss our hadronization formalism, its implementation in a Monte Carlo package, and some first results.

Session 6 / **34**

Jet overview

Author: Brian Cole[1]

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TBA

Session 6 / **25**

PHENIX results on reconstructed jets in p+p, d+Au, and Cu+Au collisions

Author: Arbin Timilsina[1]

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PHENIX has measured the inclusive jet spectra in p+p, d+Au, and Cu+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV and mid-rapidity. Jets were reconstructed from charged particle tracks and electromagnetic calorimeter clusters utilizing the anti-kT algorithm. The measurements are unfolded for detector

response and the p+p jets are consistent with a differential NLO cross-section calculation within the transverse momentum range p_T = 12-50 GeV/c. he nuclear modification factor for centrality integrated data in deuteron-gold collisions is found to be consistent with unity, strongly limiting the role of initial or final state effects. However, the centrality-selected modification factor shows substantial deviations from unity, with a qualitative pattern similar that observed at the LHC albeit at a smaller momentum. These measurements provide crucial new information for understanding the anomalous relationship between hard and soft processes in p/d+A systems. Meanwhile the Cu+Au collision system offers an intermediate testing ground for heavy ion jet reconstruction between small systems and those with the largest heavy ions. The underlying event in Cu+Au events is smaller when compared to that in the largest heavy ion systems, simplifying the extraction of the jet signals, but still achieving the large energy densities needed to drive substantial in-medium energy loss. We show the large suppression in central heavy ion events against a variety of energy loss theoretical calculations.

Session 6 / **38**

Characterization of Jets in Heavy Ion Collisions with CMS

Author: Sevil Salur[1]

[1] *Rutgers University*

Jet physics in heavy ion collisions is a rich field which has been rapidly evolving since the first observations of medium interactions at RHIC through back to back hadron correlations and at LHC via reconstructed jets. In order to completely characterize the final state via jet-medium interactions and distinguish between competing energy loss mechanisms, complementary and robust jet observables are investigated. In this talk, we will discuss the latest developments of jet finding techniques and their applications to heavy ion environments to differentiate parton flavour with emphasis on experimental results from CMS Experiment.

Session 7 / **15**

Heavy Flavor Transport in QCD Matter

Author: Ralf Rapp[1]

[1] *Texas A and M University*

Measurements of heavy-flavor particles encode unique insights into the properties and interactions of QCD matter, enabling systematic investigations as a function of the resolution scale from vanishing to large momenta. This includes the heavy-flavor diffusion coefficient as a low-momentum measure of the medium's coupling strength, the effects of recombination of heavy quarks with thermal partons as a measure of hadronization mechanisms and the change in degrees of freedom in the system, and the parton energy loss transport coefficient to characterize the coupling strength at high pt. We discuss various theoretical approaches to evalaute these properties and estimate values for the transport coefficients resulting from current model-to-data comparisons. We also estimate the momentum scales where radiative processes for charm and for bottom quarks become relevant.

Session 7 / **6**

Charm dynamics in the partonic and hadronic medium

Author: Elena Bratkovskaya[1]

[1] *GSI and Uni. Frankfurt*

We study charm production in ultra-relativistic heavy-ion collisions by using the Parton-Hadron-String Dynamics (PHSD) transport approach. The initial charm quarks are produced by the Pythia event generator tuned to fit the transverse momentum spectrum and rapidity distribution of charm quarks from Fixed-Order Next-to-Leading Logarithm (FONLL) calculations taking into account the (anti-)shadowing incorporated in the EPS09 package.

The produced charm quarks scatter in the quark-gluon plasma (QGP) with the off-shell partons whose masses and widths are given by the Dynamical Quasi-Particle Model (DQPM), which reproduces the lattice QCD equation-of-state in thermal equilibrium. The relevant cross sections are calculated in a consistent way by employing the effective propagators and couplings from the DQPM. Close to the critical energy density of the phase transition, the charm quarks are hadronized into D mesons through coalescence and fragmentation. The hadronized D mesons then interact with the various hadrons in the hadronic phase with cross sections calculated in an effective lagrangian approach with heavy-quark spin symmetry. The nuclear modification factor R_{AA} and the elliptic flow v_2 of D^0 mesons from PHSD are compared with the experimental data from the STAR Collaboration for Au+Au collisions at $\sqrt{s_{NN}}$ =200 GeV and to the ALICE data for Pb+Pb collisions at $\sqrt{s_{NN}}$ =2.76 TeV.

We find that in the PHSD the energy loss of D mesons at high p_T can be dominantly attributed to partonic scattering while the actual shape of R_{AA} versus p_T reflects the heavy-quark hadronization scenario, i.e. coalescence versus fragmentation. Also the hadronic rescattering is important for the R_{AA} at low p_T and enhances the D-meson elliptic flow v_2.

Session 7 / **4**

Recent results on heavy quark physics

Author: Joerg Aichelin[1]

[1] *SUBATECH*

Heavy mesons are like jets one of the few probes which allow for studying the expansion of a plasma of quarks and gluons (QGP) created in ultra-relativistic heavy ion collisions. To do this we have to follow the heavy quarks from their production point through the QGP up to the final rescattering of heavy mesons with hadrons after the hadronization.

In our approach the interaction of heavy quarks in the QPG is calculated in pQCD with a running coupling constant and including elastic as well as radiative collisions (arXiv 1307.5270). Combining the event generator EPOS with our heavy quark approach we can present event-by-event results in which the heavy quarks feel the fluctuation of the initial condition encoded in EPOS.

We will present studies for pA in which also a (small) plasma is created to explore cold nuclear matter effects and an analysis of AA collisions. We discuss the origin of the elliptic flow of heavy quarks and the difference between the interaction of b and c quarks with the QGP. Special emphasis is put on the question of how the results depend on the effective degrees of freedom of the plasma.

Session 8 / **21**

Recent heavy flavor measurements at PHENIX at RHIC

Author: Xuan Li[1]

[1] *Los Alamos National Laboratory*

Heavy flavor and quarkonium production are important hard probes to test Quantum Chromodynamics (QCD) and measure the properties of the Quark Gluon Plasma (QGP) created in high energy heavy ion collisions. After the installation of the Forward Silicon Vertex Tracker (FVTX) in 2012, the PHENIX experiment collected large data sets of p+p, p+Al, p+Au, Cu+Au and Au+Au collisions. The FVTX dramatically improves the tracking quality in the rapidity range of 1.2< $|y|$ <2.2, with full azimuthal angle coverage. When combined with the barrel silicon vertex detector, decayed particles with a non-zero displaced vertex can be identified. This tracking upgrade provides opportunities to study cold nuclear effects especially in asymmetric nuclear interactions, heavy quark energy loss in cold nuclear medium and hot QGP, and separation of the cold nuclear effects from the hot QCD effects (eg. QGP) in heavy ion collisions. In this talk, preliminary results of the J/ψ to ψ' ratio from 200 GeV p+p, p+Al and p+Au data will be discussed. We will also present the current status of the extraction of non-prompt J/ψ from B meson decay relative to the prompt J/ψ production in Cu+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV and p+p collisions at $\sqrt{s_{NN}}$ = 510 GeV. This analysis uses the Distance of Closest Approach (DCA) of decay muons from J/ψ to the event vertex. Similar methods can be applied in other data sets and to the study of B- and D-meson semi-leptonic decays to muons. We will show the prospects for these forward and backward rapidity measurements in (asymmetric) heavy ion and p+p collisions.

Session 8 / **10**

Open heavy-favour production with ALICE at the LHC

Author: Jaime Norman[1]

[1] *University of Liverpool*

Heavy quarks (charm and beauty), produced in ultra-relativistic heavy-ion collisions, are formed in hard partonic scattering processes in the early stage of the collision, and therefore offer a unique opportunity to probe the properties of the strongly-interacting medium created. For example, the measurement of the suppression of heavy-flavour particles in Pb{Pb relative to pp collisions can probe in-medium energy loss mechanisms, and the azimuthal anisotropy of heavy-flavour particles can help understand to what extent heavy quarks participate in the collective motion of the medium. The measurement of charmed mesons in pp and p-Pb collisions as a function of multiplicity can also help understand the role of multi-parton interactions in heavy-flavour production.

The ALICE detector is well suited to measure charmed meson decays via hadronic channels and beauty-decay electrons at mid-rapidity, as well as inclusive measurements of heavy-flavour production via semi-electronic decays at mid-rapidity, and semi-muonic decays at forward rapidity. This talk will give an overview of heavy-flavour measurements made with the ALICE detector during Run 1 in pp, p-Pb and Pb-Pb collisions, as well as outline current and future perspectives for Run 2.

Session 8 / **20**

Quenching of heavy flavors at the LHC

Author: Hongxi Xing[1]

[1] *Los Alamos National Laboratory*

Theoretical and experimental advances in understanding light jet/hadron production and modification in Pb+Pb reactions have been a highlight of the LHC heavy ion program. At the same time, the detailed mechanisms of heavy quark propagation and energy loss in dense QCD matter are not yet fully understood. With this motivation, we present theoretical predictions for the nuclear-induced

attenuation of the differential cross section for inclusive b-jet production in heavy ion collisions and comparison to CMS data [1]. We find that the attenuation is comparable to the one observed for light jets in the large transverse momentum region. We then extend this study to photon and B-meson tagged b-jet to enhance the sample of events with heavy quarks produced at the early stages of the collision. Theoretical predictions for the quenching of such tagged b-jet events at the LHC and the QGP-induced modification of the related momentum imbalance and asymmetry are presented [2]. We find these tagged b-jets have a much more direct connection to the b-quark energy loss. To facilitate further constrain of the flavor origin of final state observed heavy flavor particles, we present our calculation for heavy meson production inside jets by using Soft Collinear Effective Theory [3]. We find that the jet fragmentation function for heavy meson production is very sensitive to the gluon-to-heavy-meson fragmentation function, which can be used to clarify which aspects of heavy flavor dynamics are probed in heavy ion reactions at the LHC.

[1]. J. Huang, Z. Kang and I. Vitev, Phys. Lett. B726, 251.
[2]. J. Huang, Z. Kang, I. Vitev and H. Xing, Phys. Lett. B750, 287.
[3]. Y. Chien, Z. Kang, F. Ringer, I. Vitev and H. Xing, arXiv: 1512.06851.

Session 9 / **37**

Prompt-photon production in hadron collisions at NLO and with parton showers

Author: Michael Klasen[1]

[1] *University of Muenster*

Photon production, also in association with jets, is an important probe of the quark gluon plasma. For many decades, theoretical predictions of prompt photon production have been based on next-to-leading order (NLO) calculations. We present a recalculation of this process at NLO and combine it with parton showers (PS) in the POWHEG framework. This allows for the first time full NLO+PS simulations, including also hadronisation and detector effects. Of particular phenomenological importance are the induced modifications of the transverse-momentum balance and azimuthal angle asymmetry between the photon and recoiling jet, present now already in pp and not only in AA collisions.

Session 9 / **28**

Toward a Gamma-Jet Measurement at the STAR Experiment

Author: Saskia Mioduszewski[1]

[1] *Texas A and M University*

Hard probes are often analyzed to study the properties of the matter created in heavy-ion collisions, by comparing the measurements to those in p+p collisions. Direct photons, those produced during the collision rather than from decays of hadrons, are particularly interesting because they do not interact strongly and thus are not affected significantly by the medium. With the photon energy as a good approximation for the initial energy of the recoil parton (before interaction with the medium), the study of direct-photon-triggered away-side jets can give information about the energy loss of the recoil parton while traversing through the medium. In addition, it is useful to compare the suppression of jet-associated yields for direct-photon and neutral-pion triggers, in order to analyze the path-length and color-factor dependence of parton energy loss.

Correlation measurements of direct-photon+hadron and neutral-pion+hadron will be presented and discussed. The status of an analysis of neutral-triggered reconstructed jets will also be discussed.

Session 9 / **36**

Jet Modification Seen Through Photon-Hadron and Di-Hadron Correlations

Author: Justin Frantz[1]

[1] *Ohio University*

Two particle jet correlations, especially those involving prompt photons remain an important probe of jet quenching, complementary to full jet reconstruction measurements, especially at the lowest jet energies accessible in relativistic heavy ion collisions. For gamma-jet processes, this is due to the fact that the photon can escape unbiased by the geometry of the quenching fireball, and that the processes producing prompt photons together with jets, can tag specific flavor possibilities for the accompanying jets, such as samples of dominantly quark jets. Such measurements will continue to play an important role in the field as we search for the point where quenching effects turn off as we reduce the size of the fireball geometry going to toward smaller system sizes. We will review the latest developments in these studies at RHIC and LHC.

Session 10 / **5**

Photon production from gluon fusion with magnetic fields

Author: Alejandro Ayala[1]

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I study the enhancement of the photon production rate from gluon fusion processes, with and without thermal effects, in semicentral heavy ion collisions, where a sizable magnetic field is present.

Session 10 / **27**

Measurements of direct-photon and neutral pions azimuthal anisotropy at RHIC and LHC

Author: Ahmed Hamed[1]

[1] *University of Mississippi/Texas A and M University/HCT*

Many observations have indicated that the fragmentation functions in nucleus-nucleus collisions are softened compared to that in proton-proton collisions. Different theoretical models have been proposed in order to describe the observed phenomena. For a deeper insight into the underlying physics and better constraints for the extracted parameters of the medium formed in nucleus-nucleus collisions, a calibrated probe is needed. Direct photons act as such probes, providing experimental tools to explore energy loss of hard-scattered patrons.

We report direct-photon and neutral pions azimuthal anisotropy as a function of transverse momentum at mid-rapidity with event plane reconstructed from particles at forward rapidity in Au+Au collisions measured using STAR detector. We also show the measured direct-photon and neutral pions azimuthal anisotropy at RHIC and LHC. The results will be discussed in the scope of current theoretical models.

Session 10 / **11**

3-jet events in DIS at small x

Author: Jamal Jalilian-Marian[1]

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We calculate the cross section for production of three partons in scattering of (real or virtual) photons on a proton or nucleus target at high energy using the Color Glass Condensate formalism. We investigate the azimuthal angular correlations among the three produced partons and show that they are a sensitive probe of saturation dynamics. We outline how this cross section can be used to calculate the Next to Leading Order corrections to di-jet angular correlations at high energy.

Session 11 / **18**

Asymmetry and momentum imbalance in heavy-ion collisions

Author: Maria Tejeda-Yeomans[1]

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We study momentum imbalance as a function of jet asymmetry in high-energy heavy-ion collisions. We produce high momentum partons using 2->2 and 2->3 pQCD LO events. The produced partons lose energy within the QGP and hadronize collinearly when they leave it. The energy and momentum deposited into the plasma are described using linear viscous hydrodynamics. We find that the shape of the asymmetry observed by the CERN-CMS Collaboration can be attributed to parton energy loss in the medium and that a good description of data is achieved when a large portion of the jet events is originated from 2->2 parton events but that this description improves when we include a small but sizable contribution from 2->3 parton processes. We also show a summary of on-going extensions to this work in the study of transport coefficients and flow.

Session 11 / **14**

Surface Bias Studies with Monte Carlo Models and Application to Jet-Hadron Correlations

Author: Michael Oliver[1]

[1] *Yale University*

To make sense of correlation studies of heavy ion collisions, it is important to understand how the choice of trigger and physical cuts affects the origin of the measured particles, as this effects the path length they encounter in the medium of a quark-gluon plasma. High momentum particles are likely to have come from a QCD hard scattering process, and can thus be understood through jet-medium interaction models such as YaJEM and JEWEL. Here, we study and compare how such models predict the original vertices are distributed, given different triggers and cuts. Additionally, we apply these models to make predictions for jet-hadron correlations in colliding systems at RHIC and the LHC.

Session 11 / **12**

Jets in d(p)+A Collisions: Color Transparency or Energy Conservation

Author: Michael Kordell[1]

[1] *Wayne State University*

The production of jets, and high momentum hadrons from jets, produced in deuteron (d)-Au collisions at the relativistic heavy-ion collider (RHIC) and proton (p)-Pb collisions at the large hadron collider (LHC) are studied as a function of \emph{centrality}, a measure of the impact parameter of the collision.

A modified version of the event generator PYTHIA, widely used to simulate p-p collisions, is used in conjunction with a nuclear Monte-Carlo event generator which simulates the locations of the nucleons within a large nucleus. We demonstrate how events with a hard jet may be simulated, in such a way that the parton distribution function of the projectile is frozen during its interaction with the extended nucleus. Using our approach, we demonstrate that the puzzling enhancement seen in peripheral events at RHIC and the LHC, as well as the suppression seen in central events at the LHC are mainly due to \emph{mis}-binning of central and semi-central events, containing a jet, as peripheral events. This occurs due to the suppression of soft particle production away from the jet, caused by the depletion of energy available in a nucleon of the deuteron (in d-Au at RHIC) or in the proton (in p-Pb at LHC), after the production of a hard jet. We conclude that partonic correlations built out of simple energy conservation are mostly responsible for such an effect.

Session 12 / **33**

Di-Jet Imbalance Measurements in Central Au+Au Collisions at $\sqrt{s_{NN}}$ =200~GeV from STAR

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The transverse momentum di-jet imbalance A_J presents a powerful and robust tool to explore the strong medium modification that has been found in central 200 GeV Au+Au collisions at RHIC in numerous statistical observables. In the presented study, we focus on a set of di-jets biased toward imbalance by requiring $p_T > 20$~GeV/c for the leading jet, $p_T > 10$~GeV/c for the sub-leading jet, and $p_T > 2$~GeV/c for the constituents of the jets as well as a 5 GeV particle in the calorimeter to trigger the event. This constituent cut drastically reduces the underlying heavy ion background and leads to di-jet event-by-event selection. We then examine the evolution of A_J when reclustering these same di-jets with lower constituent cuts, until, at 200 MeV and for a resolution parameter of $R = 0.4$, all lost energy is seemingly recovered and the balance is restored to the level of pp collisions. In addition, a variation of R gives access to the angular dependence of jet energy loss.

Comparing these results to established LHC measurements enables new discussions and constraints of the underlying energy loss mechanisms that lead to the observed softening and broadening of jets in the strongly interacting medium created in heavy-ion collisions.

Session 12 / **13**

Methods for precision measurements in di-hadron and jet-hadron correlations

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Di-hadron correlations and jet-hadron correlations are useful tools for studying interactions between jets and the strongly interacting medium created in high energy heavy ion collisions. Jet-hadron correlations will be particularly useful for measurements of the low momentum component of jets. However, the background in these studies are large and are correlated with the signal. The standard method for background subtraction relies on independent measurements of the v_n. Higher order v_n are frequently not available, for instance for studies of jets, and the resulting studies therefore have large systematic errors. We present a method for determining the background by fitting the background-dominated region using the reaction plane dependence of the correlation function. We discuss methods for extending this method to lower momenta and prospects for reanalizing RHIC measurements previously analyzed assuming v_3 = 0.

Session 13 / **41**

Finite size effects in pair production processes

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Abstract: Flux tube based models are widely used for describing the early stage of heavy-ion collisions. Usually, the microscopic process underlying these models is based on vacuum pair production. In the simplest case, when the gauge field is constant and homogeneous the rate of pairs is given by the Schwinger formula. However, such energetic nucleus collisions are expected to give rise to strongly time dependent and localized fields. Using the Dirac-Heisenberg-Wigner formalism with the color-democracy assumption, we argue, that the inhomogeneous fields, like the ones in a flux tube geometry give qualitatively different spectra compared to homogeneous pair production models. We show, that the two classes can be separated by measuring the high-pT transverse spectra.

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Session 13 / **30**

Consistency of perfect fluidity and high pT parton propagation in semi-quark-gluon-monopole plasmas

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In analyzing high pT parton propagation in QGPs, a majority of perturbative QCD (pQCD) based models currently face two significant challenges: (1) simultaneously describing data of high pT single hadrons' RAA + v2 at RHIC + LHC; (2) explaining the "perfect fluid" like shear viscous transport properties of the sQGP. To overcome both, we build a new phenomenological framework – CUJET3.0 – where the full nonperturbative chromo-electromagnetic structure of the sQGP in the critical transition regime is lattice-compatibly embedded in a microscopic semi-Quark-Gluon-Monopole Plasma (sQGMP) model, and where the sQGMP is systematically integrated into a pQCD energy loss framework for jet quenching studies.

We show that this CUJET3.0 (= pQCD + sQGMP) framework solves both puzzles thanks to a dominating magnetic monopole component of the matter near Tc. More significantly, it provides a quantitative connection between the shear viscosity (η/s) and the jet transport parameter (qhat) that enables

one to deduce the T = 160–600 MeV dependence of the QGP's η/s from high pT data constrained qhat.

We further study the effects that the detailed composition of chromo-electric charges and chromo-magnetic monopoles in the near-Tc regime has on high pT light hadron and open heavy flavor observables, and provide results based on the sQGMP model that can be tested with future RHIC and LHC measurements.

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Session 13 / **8**

The next Heavy Ion Jet INteraction Generator: HIJING++

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The popular HIJING event generator is redesigned to match the compatibility with ALIROOT and is rewritten to C++. We review here the design of the C++ interface and the connections to the PYTHIA 8 event generator. Furthermore, with the development new physics is also introduced, like the inclusion of new particle distribution functions, the DGLAP evolution of the shadowing effect, different jet-quenching models.

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Session 14 / **42**

What have we learned from high pT?

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I will summarize what we have learned from measurements at high pT, and discuss some open questions. Simple observables such as single hadron RAA already proved very interesting, showing a large energy loss in the plasma and an unexpectedly flat shape with pT. Measurements have now reached sufficient precision to allow conclusions about the fractional energy shift and extraction of medium transport parameters. The quark mass dependence of RAA allows us to quantify the role of collisional energy loss. There have recently been tremendous strides in measuring medium modification of the jet fragmentation function. There is clear experimental evidence for emission of low z fragments at large angles, though there remain differences between LHC and RHIC that must be better understood. Nevertheless, the data have inspired new theoretical treatment of parton branchings and the resulting in-medium cascades. The physics of energy transport in hot

plasma and cold nuclear matter is clearly related, and better understanding of parton-plasma interactions can provide insights into the mechanism for thermalization in the early stage of a heavy ion collision.

Session 14 / **43**

Joint LHC/sPHENIX perspective for jet physics in the 2020's

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