

Identifying the underlying physics of the ridge via 3-particle $\Delta\eta - \Delta\eta$ correlations in STAR

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Dihadron correlations provide a powerful tool to study the properties of the medium created at RHIC. One of the novel observations is the formation of the near-side ridge, where hadrons are correlated with a high transverse momentum (p_T) trigger particle in the azimuthal angle ($\Delta\phi \sim 0$) but distributed approximately uniformly in pseudorapidity ($\Delta\eta$). This observation has prompted many theoretical investigations, including longitudinal flow push, QCD bremsstrahlung radiation boosted by transverse flow, recombination between thermal and shower partons at intermediate p_T , broadening of quenched jets in turbulent color fields, elastic collision between hard and medium partons (momentum kick) and back splash from the away-side stopped parton. To potentially discriminate between these different physics mechanisms we present the first study of 3-particle correlation in $\Delta\eta$ - $\Delta\eta$ by the STAR experiment. Preliminary results will be presented for $Au + Au$ and $d+Au$ collisions at $\sqrt{s_{NN}} = 200$ GeV. The results are studied as a function of trigger ($p_T > 3$ GeV/ c) and associated particle ($p_T > 1$ GeV/ c) p_T and collision centrality. Implications of the results in the context of the theoretical models will be discussed.

The Ridge in near side two particle correlations

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The near-side distribution of particles at intermediate transverse momentum, associated with a high momentum trigger hadron produced in a high energy heavy-ion collision, is broadened in rapidity compared with the jet cone. This broadened distribution is understood in terms of the energy lost by the progenitor parton of the trigger hadron. The broadening is shown to result as the final-state deflection of the gluons radiated from the hard parton inside the medium by soft turbulent color fields that arise in the presence of plasma instabilities. A detailed study of this ridge like structure based on perturbative QCD and multi-hadron fragmentation functions is presented. The magnitude of the broadening is found to grow with medium size and density and diminish with increasing energy of the associated hadron. For trigger and associated hadrons at high enough energies, the multiplicity in the ridge component is shown to contain the hadrons fragmenting mostly from the radiated gluon.

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The STAR Collaboration observed a $\Delta\phi$ - $\Delta\eta$ correlation of particles associated with a near-side jet in RHIC collisions [1-4]. The correlation exhibits a near-side jet component at $(\Delta\phi, \Delta\eta) \sim (0, 0)$ and a ridge component at $\Delta\phi \sim 0$ with a ridge structure along $\Delta\eta$.

The ridge particles bear characteristics similar to those of inclusive particles. Their $\Delta\phi \sim 0$ correlation with the trigger jet suggests that the ridge particles and the jet are related kinematically. It is therefore reasonable to propose the momentum kick model [5] in which the ridge particles are identified as medium partons which suffer a collision with the jet and acquire a momentum kick q along the jet direction. The yield of the ridge particles associated with the jet will depend on the momentum kick q and the initial parton momentum distribution, parametrized as $dN/dyp_t dp_t d\phi = A \exp\{-y^2/2\sigma_y^2\} \exp\{-\sqrt{m^2 + p_t^2}/T\} / \sqrt{m^2 + p_t^2}$ with a rapidity width parameter σ_y and a temperature parameter T .

Under the action of a jet-parton momentum kick, a peak structure in $\Delta\phi$ arises because (i) the magnitude of the initial transverse momentum p_{ti} is a minimum at $\Delta\phi = 0$, and (ii) the probability distribution of the initial transverse momentum p_{ti} decreases as p_{ti} increases. The width of the $\Delta\phi$ distribution of ridge particles depends on q . The ridge structure along the $\Delta\eta$ direction depends on σ_y and reflects the initial rapidity distribution at the momentum of the jet-parton collision.

We found that a momentum kick $q = 0.8$ GeV, an initial rapidity width $\sigma_y = 5.5$, and an initial temperature $T = 0.47$ GeV give a good description with the ridge part of the experimental data [2] in Fig. 1, where the theoretical momentum kick model results for the ridge part of particle yields are shown as solid curves.

If the momentum kick model is indeed the correct mechanism, the ridge structure associated with the near-side jet holds the fascinating promise as a tool to probe the early parton momentum distribution at the moment of the jet-parton collision, leading to the result that at that instant the parton temperature is slightly higher and the rapidity width substantially greater than corresponding quantities at the end point of the nucleus-nucleus collision [5].

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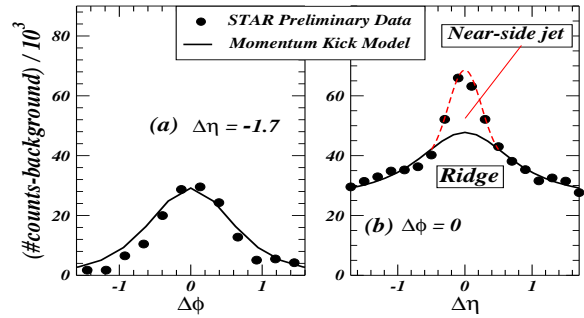


Fig. 1

VISCOSITY AND THE SOFT RIDGE AT RHIC

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Measurements at RHIC reveal a near-side ridge in pseudorapidity and azimuthal angle for particle production associated with a high p_t particle [1]. This phenomenon has been attributed to interactions of the jet with matter. Interestingly, two particle correlation measurements show a similar ridge-like feature *without* the jet tag [2]. This soft ridge becomes broader in pseudo-rapidity with increasing centrality, while narrowing in azimuthal angle – trends shared by the jet-associated ridge.

In this talk we show that viscous hydrodynamic flow can explain the soft-ridge feature along with other characteristics of two particle correlation measurements. We have attributed the rapidity broadening of the soft ridge to viscous diffusion, and used it to extract a value of the shear viscosity to entropy ratio in the range $0.08 < \eta/s < 0.3$ [3]. This very small value is precipitously close to the AdS/CFT bound of $1/4\pi$. Here, we extend this work to address the full behavior of two particle-correlations in azimuthal angle and rapidity. Specifically, we solve viscous hydrodynamic equations including radial and elliptic flow. Results are shown to be consistent with the centrality dependence found in average transverse momentum $\langle p_t \rangle$ and elliptic flow v_2 measurements. We use these results to build a consistent picture of the soft ridge, and show how correlation measurements can greatly reduce the current uncertainty in the measured shear viscosity. We then discuss the relation of the soft ridge to its jet-associated cousin.

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SEARCH FOR A RIDGE STRUCTURE ORIGIN WITH SHOWER BROADENING AND JET QUENCHING

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Recently, an interesting structure is discovered in two particle ϕ - η correlation at RHIC. This structure, which is called ridge structure, have narrow and broad widths in ϕ and η directions, respectively [1]. Since ridge cannot be understood in simple jet fragmentation, various pictures have been proposed so far [2,3]. Firstly, to explore the origin of the ridge structure, we investigate two-hadron correlations in a jet-fluid string (JFS) model which is suggested to work in high p_T region. In a present treatment, a jet parton loses its energy in QGP, and forms a string with a fluid parton when it goes out from QGP. Finally, hadrons are formed by string fragmentation. It is demonstrated that this model explains jet quenching, large elliptic flows at high p_T and suppression of the back-to-back correlation simultaneously [4]. However, we find that we cannot describe the ridge structure in two particle ϕ - η correlation in JFS. We have recently found that broadening of shower partons before thermalization [5] followed by parton energy loss could generate a ridge-like structure. Strong color electric and magnetic fields just after collisions (the so-called Glasma) can be attributed to the broadening phenomenon. As a result of the energy loss, correlations at large $\Delta\phi$ are suppressed, then the ridge-like structures are left.

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JET-RIDGE EFFECT AS A BACK SPLASH FROM STOPPED PARTON

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I propose a simple explanation of the “ridge” seen in the near-side jet two-particle correlation function in heavy ion collisions at RHIC [1]. This could be a cumulative shock wave produced in liquid-like matter by an energetic stopped parton. Splash of liquid in the direction opposite to the fast penetrating object is a known effect. In nucleus-nucleus collision the trigger is an escaped non-interacting parton. Partner parton could be stopped in the medium forming a conical-like volume tension which will generate shock waves. In the proposed scenario [2] shock waves will move in three directions: two waves will move out-wards forming a collective mode which is usually called a Mach Cone. Conical volume tension will also released in-wards the cone, where shock waves will interfere and form a back splash in the direction exactly opposite to the original direction of stopping parton. Thus, we state that observations of the Mack cone and the ridge have the same origin and are produced by stopped parton. Many experimental observations become clear in a such scenario. The wide rapidity distribution of the ridge is explained by the rapidity swing of the away-side jet and longitudinal expansion of the system along the beam direction. Surface bias of the trigger particle leads to a significant contribution from nucleus corona region to the back splash, thus making the ridge yield almost momentum independent of the trigger particle. Intensity of the ridge should

depend only on probability of absorbing the away-side jet, which agrees with the observed centrality dependence on the ridge yield. The ridge should exhibit very similar properties as the bulk matter, but because of some velocity boost, the particle spectrum from the ridge should be harder than the inclusive spectrum. Also observed experimentally. Mach cone - ridge structure should persist in particle correlations to the lowest particle momentum. This explains three-hump structures experimentally seen in the azimuthal distributions at very low particle momentum. Three particle correlations in pseudo-rapidity should have strong positive rapidity correlation of two particles relative to the trigger particle. Hard direct photon-hadron correlation should also demonstrate the near side ridge and the Mach cone, though may be suppressed by the thermalization in the bulk matter. The calculation of such a shock wave in the form of back splash is very complicated, but some phenomenological observables could be explained and predicted.

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Jet shape broadening and quenching versus rapidity

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The jet shape modification due to partonic energy loss in the dense QCD matter is investigated by the help of the special transverse energy-energy correlator in the vicinity of maximum energy deposition of every event. In the accepted scenario with scattering of jet hard partons off comoving medium constituents this correlator is independent of the pseudorapidity position of a jet axis and becomes considerably broader (symmetrically over the pseudorapidity and the azimuthal angle) in comparison with pp -collisions.

At scattering off “slow” medium constituents the broadening of correlation functions is dependent on the pseudorapidity position of a jet axis and increases noticeably in comparison with the previous scenario for jets with large enough pseudorapidities. These two considered scenarios result also in the different dependence of jet quenching on the pseudorapidity.

High- p_T Triggered $\Delta\eta$ - $\Delta\phi$ Correlations in Au+Au Collisions

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We present the first measurement of pseudorapidity ($\Delta\eta$) and azimuthal angle ($\Delta\phi$) correlations between high transverse momentum charged hadrons ($p_T > 2.5$ GeV/c) and

associated particles at both short- (small $\Delta\eta$) and long-range (large $\Delta\eta$) over a continuous pseudorapidity acceptance ($-4 < \Delta\eta < 2$).

The study of correlations with respect to high- p_T particles is a powerful tool for examining the modification of jets as they interact with the hot and dense medium created in heavy ion collisions. In this talk we explore the various near- and away-side features of the correlation structure as a function of centrality in 200 GeV Au+Au collisions. In particular, this measurement allows us to determine much more completely the longitudinal extent of the “ridge” structure first observed by the STAR collaboration over a limited η range [1].

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The “Shoulder” and the “Ridge” in PHENIX: Medium Response to Fast Partons in Heavy Ion Collisions via Di-hadron Correlations

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The observation of jet quenching in ultra-relativistic heavy ion collisions demonstrates significant energy loss of fast partons when passing through the created medium. Correlations between final-state hadrons at intermediate transverse momentum ($1.0 < p_T < 4.0 \text{ GeV}/c$) allow for detailed study of the medium and its response to deposited energy. Comparison of these measurements in heavy ion collisions with baseline measurements in proton collisions show strong modification of the correlation shape and particle yields. Two new structures are created, both extended in $\Delta\eta$, one centered at $\Delta\phi = 0$ (“ridge”) and the other occurring at $\Delta\phi \approx \pi \pm 1.1$ (“shoulder”).

Decomposition of the away-side distributions to quantify the medium response to the passage of a fast parton will be discussed. New PHENIX results in particle yields and spectra within the “shoulder” are consistent with a scenario of parton-medium interaction. Including work on the most recent Run7 data set, we will present new analysis on the path-length, angle relative to reaction plane, particle ID, and p_T dependence of hadrons with a specific focus on how the medium responds to fast partons in Cu+Cu and Au+Au collisions. The status of 3 particle correlations and first direct PHENIX analysis of near-side “ridge” correlations will also be reported. In order to extract as much information on the medium response as possible, the data will be compared to baseline p+p results and theoretical predictions.

BARYON AND MESON PRODUCTION IN JETS AND RIDGES FROM STAR

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One of the novel features observed in the ultra-relativistic heavy ion collisions at RHIC is a significant enhancement of relative baryon production apparent in the intermediate momentum range of 2 to 5 GeV/c. The baryon over meson ratios in this kinematic domain exceed the observations from pp collisions by factor of 2. In this transition range from bulk soft physics to the high momenta where jet fragmentation is believed to be the dominant mechanism of hadronization, we explore jet-medium interactions as possible mechanism for baryon enhancement.

In this talk, we study baryon and meson (\bar{p} , p and π^\pm) spectra and ratios in the di-hadron correlations with high- p_T hadron trigger. We will discuss the differences between the inclusive (non-triggered) ratios from 200 GeV central Au+Au collisions and the observed ratios in jet and ridge parts of 2-dimensional di-hadron $\Delta\phi$ - $\Delta\eta$ correlations. We will discuss these results in conjunction with our measurements from d+Au collisions, also we will compare the ratios to those from inclusive pp and e^+e^- data and various models for energy loss.

Away-side Modification and Near-side Ridge Relative to Reaction Plane

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Di-hadron correlations are sensitive to the properties of the matter created at RHIC due to strong interactions of the traversing parton with the medium (jet quenching). Previous measurements have revealed two novel phenomena in Au+Au collisions: the away-side correlation is double-peaked and the near-side correlation is atop of a long range $\Delta\eta$ ridge. In this talk, we investigate the geometry dependence of these phenomena by studying dihadron correlations as a function of the trigger particle azimuthal angle relative to the reaction plane ($\Delta\phi_{T-RP}$). The mid-central (20-60%) and central (top 5%) Au+Au collisions taken in year 4 by STAR are used; the d+Au data are used as reference. The trigger and associated p_T dependences of the correlation functions are studied. Our measurements bring new insights into the two novel phenomena observed in inclusive dihadron correlations:

- (i) The away-side correlation broadens (and becomes double-peaked) with increasing $\Delta\phi_{T-RP}$ in 20-60% collisions. In top 5% collisions, the away-side correlation is broader at small $\Delta\phi_{T-RP}$, but at $\sim 90^\circ$ little difference is found between the two centralities, perhaps consistent with the variations in the away-side medium pathlength.
- (ii) The near-side jet component varies little with $\Delta\phi_{T-RP}$ and generally agrees with d+Au. However, the ridge component decreases significantly with $\Delta\phi_{T-RP}$ in 20-60% collisions. The change is weaker in top 5% collisions, consistent with the more spherical geometry.

Investigation of our results in theoretical frameworks will hopefully help further our understanding of the physics mechanisms underlying jet-quenching and the medium properties at RHIC.

Investigating hadronization and medium-induced fragmentation modification in A+A collisions with high- p_T jet correlations in PHENIX

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Angular correlations between high- p_T particles associated with partonic jet fragmentation provide an important opportunity to study the properties of the hot, dense medium produced in $A+A$ collisions. Correlations involving identified particles allow the possibility to differentiate quark and gluon fragmentation processes, yielding data which informs recombination scenarios and models describing interactions between hard-scattered and thermal particles. In $p+p$ collisions, recent progress has been made in correlations involving identified fragmentation photons, potentially improving differentiation between quark and gluon fragmentation since bremsstrahlung photons should be radiated by only the quarks to first order. The status of this analysis, the first of its kind and also an important baseline for bremsstrahlung enhancement predicted for $A+A$, will be presented. Further, fragmentation and kinematic observables such as x_E , p_{out} , and z_T characterize the momentum distribution of hadrons within jets and assist in constraining models describing jet-medium interactions by comparing such quantities between $A+A$ data and a $p+p$ reference. The slopes of these distributions provide additional information on fragmentation modification. New results on jet correlation analyses from the PHENIX experiment involving high- p_T π^0 s with identified and unidentified associated particles are presented from Run 7 Au+Au data, which features a threefold enhancement in statistics over Run 4, extending the kinematic range of the fragmentation observables.

BACK-TO-BACK DI-JET TRIGGERED MULTI-HADRON CORRELATIONS AS MEDIUM PROBES IN STAR

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Experimental studies of QCD medium created in ultra-relativistic heavy ion collisions at RHIC have supplied the evidences of jet-quenching, where significant amount of jet initial energy is being deposited in the created strongly interacting partonic medium. The effects of the jet-medium interactions are apparent, for instance, in the away-side distributions of associate hadrons in di-hadron azimuthal correlation studies. Believed to be due to the response of the medium to jets propagating through it, various physical mechanisms (mach cone shock wave, Cerenkov gluon radiation, jet deflection and others) have been proposed to explain the experimental observations.

In this talk, a new three-particle correlation technique from STAR is used to study jets and jet

energy loss mechanisms in ultra-relativistic Au+Au collisions. We use a pair of approximately back-to-back high-pt hadrons to restrict the di-jet kinematics and study associated particles with respect to the di-hadron trigger. For the first time for soft associate hadrons, we show that the away-side correlation structure is also peaked in $d\eta$ as well as $d\phi$, which further confirms the di-jet nature of these events. By varying the away-side trigger threshold, we vary the 'surface bias' and the trigger bias on in-medium energy loss, thus providing differential measurements of the energy loss process. The measurements in Au+Au collisions are compared to a d+Au reference to quantify dijet suppression.

System size dependence of jet-like di-hadron correlations in Au+Au and Cu+Cu collisions in STAR

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Results from the experiments at RHIC have shown evidence that a strongly interacting medium is formed in ultra-relativistic heavy ion collisions at RHIC energies. The strongest evidence comes from jet-like di-hadron correlations, which show a strong suppression of the away-side yield in heavy ion collisions but not in d+Au collisions.

We present a systematic study of the near- and away-side di-hadron correlation yields, as a function of number of participant nucleons (N_{part}), for 3 systems with different geometries: d+Au, Au+Au and Cu+Cu, at $\sqrt{s_{NN}} = 200 GeV$ as measured in STAR. Taking the method one step further, we investigate the modification of the away-side di-hadron fragmentation functions for high transverse momentum particles in Au+Au and Cu+Cu. A comparison with theoretical predictions using NLO pQCD is also presented. The calculation allows the determination of the transport coefficient of the medium (\hat{q}) using previous Au+Au data. We compare it with our data for the various centralities in Au+Au and Cu+Cu to explore the path-length dependence of energy loss.

Anomalous centrality variation of minijet angular correlations in Au-Au collisions at 62 and 200 GeV from STAR

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We have measured two-particle autocorrelations on (η, ϕ) for all unidentified charged hadrons with $p_t > 0.15 GeV/c$ and $|\eta| < 1$ from Au-Au collisions at 62 and 200 GeV. The correlation structure is dominated by a peak centered at zero relative opening angles on η and ϕ which we hypothesize is caused by minimum-bias jets (minijets). We observe a large excess of minijet correlations in more-central Au-Au collisions relative to binary-collision scaling (more correlated pairs than expected from surface emission or even volume emission and

fragmentation of scattered partons). We also observe a sudden and dramatic increase of the minijet peak amplitude and η width relative to binary-collision scaling which occurs at an energy-dependent centrality point. These results confirm a rapid transition of minijet correlation properties observed previously at 130 GeV [1]. There is a possible scaling of the transition point with transverse particle density. Systematic trends correspond well with the two-component systematics of single-particle p_t spectra, specifically the hard component and possible parton energy loss. The large increase of the minijet correlations from peripheral to central Au-Au collisions appears to be strongly inconsistent with thermalization in heavy ion collisions.

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Constraining the Geometry to Study Jet Energy Loss with 2-particle correlations vs Reaction Plane and "2+1" correlations in PHENIX

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Correlations between two high-pt hadrons provide information on how partons lose energy as they travel through the dense plasma formed at RHIC. In back-to-back jets events, where both partons survive to produce high-pt hadrons, the distribution of hard-scattering locations is likely different than the surface-bias that affects single-particle studies. Hence di-jet correlations can be used to study more of the densest region of the matter formed at RHIC, provide a better understanding of energy loss, and constrain the plasmas properties. Achieving these goals requires that we 1) control the path-length travelled by the partons as much as possible and 2) use di-jet observables that are sensitive to the amount of energy loss of partons.

To vary the path length we measure both the centrality and the trigger particle with respect to reaction. In addition, we require an a high-pt hadron in the back-hemisphere to the trigger particle, i.e. 2+1 particle correlations. We will present how two-particle correlations change as a function of these selection variables, and compare with the baseline p+p results. Our emphasis will be on those observables that are sensitive to the amount of energy loss of partons, e.g., the reduction of the yields for far-side associated hadrons as a function of reaction plane and centrality. We will also show quantities derived from these yields, such as \hat{x} , the ratio of the di-jet partons momenta after energy loss, but before fragmentation. This ratio is sensitive to the relative energy loss of the two back-to-back partons in the dense medium.

Azimuthal correlations with high-pt multi-hadron cluster triggers in Au+Au Collisions at $\sqrt{(s_{NN})} = 200$ GeV from STAR

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Di-hadron correlation measurements have been used to probe di-jet production in heavy ion collisions at RHIC. A strong suppression of the away-side high-pt yield in these measurements is direct evidence that high-pt partons lose energy as they traverse the strongly interacting medium. However, since the momentum of the trigger particle is not a good measure of the jet energy, azimuthal di-hadron correlations have limited sensitivity to the shape of the fragmentation function. We explore the possibility to better constrain the initial parton energy by using clusters of multiple high-pt hadrons in a narrow cone as the 'trigger particle' in the azimuthal correlation analysis. We present first results from this analysis of multi-hadron triggered correlated yields in Au+Au collisions at $\sqrt{(s_{NN})} = 200$ GeV from STAR. The results are compared to measurements in d+Au collisions and Pythia calculations, and the implications for energy loss and jet fragmentation are discussed.

Proton-to-pion ratio for the near-side jet in pp and AA collisions at RHIC energies

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Anomalously large values have been measured for the proton to pion ratios in $AuAu$ collisions at RHIC energies in the intermediate and high- p_T regions [1,2,3]. The one-particle spectra for both pions and protons display a suppression pattern, although a different one, which can be analyzed by induced energy loss at parton level [4]. On the other hand, quark coalescence models became very successful to reproduce these anomalous ratios [5].

Recent data on proton-proton and proton-antiproton correlations do not confirm the quark coalescence picture, but suggest a jet origin for these correlated pairs [6,7]. This contradiction of the particle origin is one of the greatest puzzles at RHIC energies.

We have analyzed two-particle correlations in pp collisions [8]. Now we extend our analysis to $AuAu$ collisions, especially in the near-side jet cone, including the effect of jet energy loss. We calculate proton to pion ratios and correlations in proton-proton and heavy-ion collisions

at RHIC energy and display the possible difference obtained in a pQCD model applying the latest fragmentation functions. We discuss the expected results at LHC energies.

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Two-particle Azimuthal Correlations of High- p_T Charged Hadrons at the CERN SPS

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Two-particle azimuthal correlations of high- p_T hadrons can serve as a probe of interactions of partons with the dense medium produced in high-energy heavy-ion collisions. First NA49 results on such correlations will be presented for central and mid-central Pb+Pb collisions at 158A GeV beam energy, for different p_T thresholds and charge combinations of trigger and associate particles; these results show a double hump shape of the away-side peak for the most central collisions, which is consistent with predictions of the medium-interaction scenario. A comparison with CERES Pb+Au results at the same energy, as well as with STAR Au+Au results at RHIC energies, will also be provided.

Conical emission: p_T and system dependences and the first result with identified protons from STAR

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Three-particle azimuthal jet-like correlations have revealed evidence for conical emission in central Au+Au collisions at RHIC. The conical emission signal, if originated from Mach cone shock waves, can yield valuable information about the properties of the created medium, such as the speed of sound and the equation of state. In this talk, we extend our 3-particle correlation measurements to four important areas: (1) we investigate the associated p_T dependence of the conical emission angle which can distinguish between Mach cone shock

waves and Čerenkov gluon radiation; (2) we vary the trigger particle p_T to change the relative correlation strengths between contributions of different origins, such as jet fragmentation and medium response; (3) we identify the associated particles by dE/dx in the STAR TPC to measure the first 3-particle azimuthal correlations of protons (baryons) with a high p_T trigger particle, which may have different physics sensitivity than that of the lighter pions (mesons); and (4) we measure 3-particle correlation in Cu+Cu collisions to investigate system dependence of conical emission. Extensive systematic studies of 3-particle correlations will be presented as a function of associated and trigger particle p_T in pp , d+Au, and A+A collisions at 200 GeV. The conical emission angle and width are studied. The k_T broadening effect is investigated by measuring the azimuthal acoplanarity. The first result on 3-particle azimuthal correlations with identified associated protons will be presented and compared to the charged hadron 3-particle correlation results. We discuss how these results will help further our understanding of the physics of jet-medium interactions at RHIC.

Jet Propagation and Mach Cones in (3+1)d Ideal Hydrodynamics

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The observation of jet quenching and associated away-side Mach Cone-like correlations at RHIC provide powerful “external” probes of the sQGP produced in A+A reactions [1]. The nearly perfect bulk fluidity observed via elliptic flow suggests that Mach Cone-like correlations may also be due to rapid local equilibration in the wake of penetrating jets. Multi-particle correlations lend further support to this possibility [2]. However, the details of the fluid response to jets are shown to depend critically on the energy, longitudinal, and transverse momentum deposition mechanisms. We solve numerically covariant 3-dimensional hydrodynamics [3] to compute the flow correlation patterns resulting from a variety of possible energy-momentum deposition models. Mach Cone flow-field correlations generically do not survive the hydro decoupling freeze-out phase. Multi-hadron Mach Cone correlations only survive for a special limited class of energy-momentum loss models which assume significantly less longitudinal momentum loss than energy loss per unit length. We conclude that the correct interpretation of away-side jet correlations will require improved under-

standing and independent experimental constraints on the jet energy–momentum loss to fluid couplings.

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Study of Conical Emission of Particles from Heavy Quark Energy Loss via Azimuthal Angle Correlations Triggered by Non-Photonic Electrons at STAR

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High- p_t partons lose a significant amount of energy when traversing the dense QCD medium created in central Au+Au collisions, which leads to the suppression of high- p_t hadron yields and changes in the azimuthal angle correlation of hadrons. A conical emission pattern has been observed in di-hadron azimuthal correlations. Study of the particle emission pattern from heavy quark energy loss in the dense QCD medium will provide insight on the mechanism responsible for the emission pattern and the flavor dependence.

In this talk, we will present STAR preliminary measurements of azimuthal correlations between non-photonic electrons and charged hadrons in Au+Au and Cu+Cu collisions at 200 GeV. The comparison between different collision systems enables us to study the system-size dependence of heavy quark energy loss and the conical emission of its associate particles.

Search for conical emission in A + A collisions with the cumulant technique.

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We report on a search for conical emission using three particle azimuthal correlation cumulants in A + A collisions at $\sqrt{s_{NN}} = 200$ GeV. The analysis reveals finite 3-particle azimuthal

correlations, dominated by near and away side particle correlations consistent with jet production, and jet-flow correlations. Evidence for weak $v_2v_2v_4$ contributions is also found. We furthermore carry flow terms subtraction from the measured cumulant to investigate the presence of conical signals.

FATE OF THE MACH-CONE FROM COVARIANT TRANSPORT THEORY

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Heavy-ion collisions offer an intriguing possibility to study collective hydrodynamic excitations generated by a fast particle moving through dense nuclear matter (so called "Mach cones") [1]. Recent data on two- and three-particle angular correlations at RHIC seem to be consistent with simple Mach-cone scenarios [2]. However, density variations, collective flow and space-time evolution of the medium, and also dissipation can strongly affect the expected signatures.

In this talk I investigate the fate of the Mach-cone from covariant transport theory[3, 4], and discuss the role of dissipation (viscosity) in this observable. The calculations will be contrasted with recent results by Ma et al [5] based on the AMPT model, which unfortunately employs the naive cascade algorithm that violates Lorentz covariance and causality [3]. (Acausal numerical artifacts in the naive cascade affect observables such as spectra, elliptic flow, and spacetime distributions [3, 4, 6, 7].) Comparisons with results from 3+1D causal dissipative hydrodynamics[8], if available by the Conference, will be also shown.

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MACH CONES IN A PERTURBATIVE QUARK-GLUON PLASMA

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We derive and evaluate the local distribution of energy and momentum deposited by a fast parton in a quark-gluon plasma in the framework of hard-thermal loop perturbation theory. We then use our result as a source term for the formation of sound waves in the plasma. We show that a Mach cone develops behind the parton in linearized dissipative hydrodynamics [1], if the parton moves faster than the speed of sound in the plasma. Finally, we explore the effects of the source term in a realistic nuclear collision within a numerical solution of three-dimensional ideal relativistic hydrodynamics [2].

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QGP COLLECTIVE EFFECTS AND JET TRANSPORT

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We study the effect of collective phenomena on jet propagation in the quark-gluon-plasma using numerical simulations of the QCD Boltzmann-Vlasov equation including both hard elastic particle collisions and soft interactions mediated by classical Yang-Mills fields. The longitudinal expansion of the plasma can lead to a strongly anisotropic oblate momentum distribution in the local rest frame. In such a system the fields develop unstable modes, forming configurations of large-amplitude turbulent chromo-fields by which the jets are deflected preferentially in the longitudinal direction. This provides a possible explanation for

the experimental observation that high-energy jets traversing the plasma perpendicular to the beam axis experience much stronger broadening in rapidity than in azimuth. [1]

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Two-particle correlations from RHIC to LHC with a new method based on Fourier Transform

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An extension to LHC energy ($\sqrt{s_{NN}} = 5.5$ TeV) for two-particle correlations (à la RHIC) is presented. In this study a parton quenching model developed in the BDMPS-Z-SW framework is considered and implemented as an afterburner for PYTHIA and HIJING. The simulation method, tuned on the RHIC data, is then used to make predictions for the LHC energy regime [1] in order to probe the scenario that we will study in the ALICE experiment. Moreover, a complementary and original method to study jet correlations is also developed based on Fourier Transform [2]. The features of the new method match the predicted LHC scenario, in particular the abundant multijet production expected at intermediate momenta in the very central PbPb collisions.

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Machcones in Heavy Ion Collisions

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We study the propagation of sound-like perturbations created by a jet moving with supersonic velocity through the quark-gluon-plasma created in heavy-ion reactions within the model MACE (MACH Cone Evolution). An advantage of this approach is that the dynamics of

the underlying medium is calculated from a (3+1)-dimensional hydrodynamical approach and the shapes of the mach cones are dynamically created by elementary waves emitted at constant time intervals. Hence, one avoids premature assumptions on the shape and evolution of these collective effects. Predictions for heavy-ion reactions at RHIC energies (Au+Au-collisions) and for Pb+Pb reactions at the LHC ($\sqrt{s} = 5.5A$ TeV) are presented and potential observations by the STAR, PHENIX and ALICE experiments are discussed.

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Jet studies in Pb-Pb at 5.5 TeV via 2- and 3- particle correlations

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Understanding the energy loss mechanisms in hot and dense QCD matter is an important aspect of phase diagram exploration at RHIC. With the start of the LHC experimental program, such studies will be taken to a new energy domain, lending crucial new insights into the created matter.

In recent years a plethora of tomographic probes have been developed in the field of experimental heavy ion collisions, in attempts to characterize the properties of the hot and dense medium created.

Multi-particle correlation techniques, that explore jet-medium interactions and allow the energy loss in the fireball to be gauged, have drawn a lot of attention in the field, and have stimulated many theoretical developments. We investigate the possibility of utilizing two- and three- particle correlation methods for probing the medium.

We will discuss characterization of the jet yields, fragmentation functions, and energy estimates on near- and away- sides in azimuthal di-hadron correlations. Studies will also be performed in $\Delta\eta$ -space, where peculiar structures (ridges) were observed at RHIC. This feasibility study of such measurements within the acceptance of the CMS detector is carried out using a Monte Carlo sample of 5.5 TeV Pb+Pb collisions.