

**FINAL TECHNICAL REPORT  
ON  
“SYSTEMATIC STUDIES OF HEAVY ION COLLISIONS  
TO SEARCH FOR QUARK-GLUON PLASMA”**

**Outstanding Junior Investigator Award  
Award No. DE-FG02-02ER41219  
Principal Investigator: Fuqiang Wang**

**Project Period: July 15, 2002 – June 14, 2007**

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November, 2007**

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## 1. EXECUTIVE SUMMARY

This is the final technical report for DOE Outstanding Junior Investigator (OJI) Award, “Systematic Studies of Heavy Ion Collisions to Search for Quark-Gluon Plasma”, grant # DE-FG02-02ER41219, Principal Investigator (PI) Fuqiang Wang.

The research under the grant was divided into two phases. The first concentrated on systematic studies of soft hadron production at low transverse momentum ( $p_T$ ), in particular the production of (anti-)baryon and strangeness in heavy ion collisions at RHIC energies. The second concentrated on measurements of di-hadron and multi-hadron jet-correlations and investigations of medium response to jets. The research was conducted at the Relativistic Heavy-Ion Collider (RHIC) at BNL with the Solenoidal Tracker At RHIC (STAR) experiment.

The total grant is \$214,000. The grant established a PC farm solely used for this research. The PC farm consists of 8 nodes with a total of 16 CPUs and 3 disk servers of total 2 TB shared storage. The current balance of the grant is \$19,985. The positive balance is because an initial purchase of \$22,600 for the PC farm came out of the PI's start-up fund due to the lateness of the award. The PC farm is an integral part of the Purdue Physics Department's computer cluster.

The grant supported two Ph.D. graduate students. Levente Molnar was supported from July 2002 to December 2003, and worked on soft hadron production. His thesis title is *Systematics of Identified Particle Production in  $pp$ ,  $d$ -Au and Au-Au Collisions at RHIC Energies*. He graduated in 2006 and now is a Postdoctoral fellow at INFN Sezione di Bari, Italy working on the ALICE experiment at the LHC. Jason Ulery was supported from January 2004 to July 2007. His thesis title is *Two- and Three-Particle Jet-Like Correlations*. He defended his thesis in October 2007 and is moving to Frankfurt University, Germany to work on the ALICE experiment at the LHC.

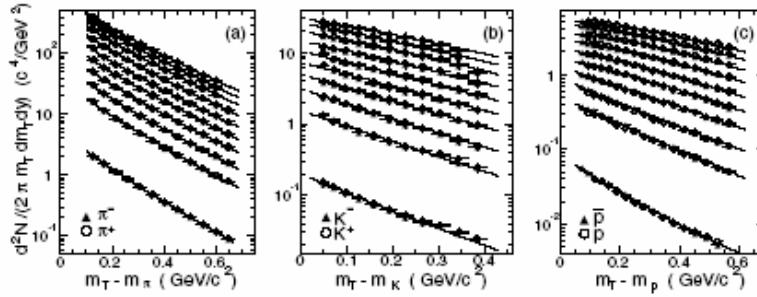
The research by this grant resulted in 7 journal publications (2 PRL, 1 PLB, 1 PRC, 2 submitted and 1 in preparation), and 14 invited talks and 10 contributed talks at major conferences. These are listed at end of this report.

## 2. PROJECT MOTIVATIONS, ACCOMPLISHMENTS AND IMPACT

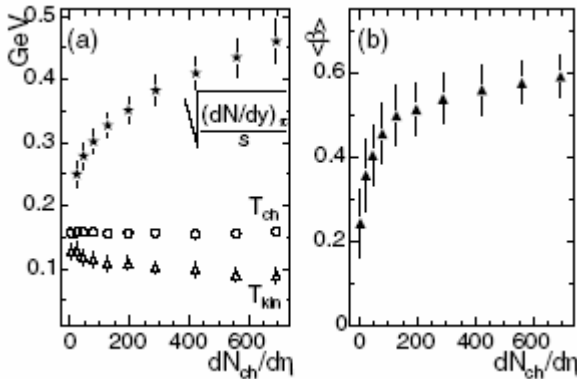
The ultimate goal of relativistic heavy-ion collisions program is to discover and study the deconfined phase of quarks and gluons, the Quark-Gluon Plasma (QGP). This grant addressed this by measuring the bulk properties of the created medium through two means: distributions of particles from direct decay of the medium and modifications to jet-correlations due to interactions of jets with the medium.

### 2.1 Measurements of Bulk Medium Properties

Lattice QCD calculation predicted that a phase-transition between hadronic matter and QGP should occur at a temperature about  $T_C=170$  MeV at zero baryo-chemical potential [1]. After phase transition, the QGP expands and cools down and hadronizes into hadrons that are measured in experiment. The momentum spectra of hadrons give information about the kinetic freeze-out temperature, after which the hadrons do not



**Figure 1.** Invariant yield as functions of transverse mass for pions, kaons, and inclusive proton and antiproton at midrapidity for p+p (bottom) and Au+Au collisions from 70-80% (second from bottom) to the 0-5% centrality bin (top). The curves shown are Bose-Einstein fits to the pion spectra and Blast-wave fits to the kaon and (anti)proton spectra. Figure from [pub3].



**Figure 2.** (a)  $\sqrt{(dN/dy)_\pi / S}$  (stars),  $T_{ch}$  (circles), and  $T_{kin}$  (triangles), and (b)  $\langle \beta \rangle$  as a function of  $dN_{ch}/d\eta$ . Errors are systematic. Figure from [pub3].

interact further and the kinetic spectra are frozen. The relative abundances of produced hadrons give information about the chemical freeze-out temperature after which hadrons do not interact inelastically any more. The chemical freeze-out temperature should not be lower than the kinetic freeze-out temperature, and should not be higher than the phase transition

temperature.

We have measured transverse momentum ( $p_T$ ) spectra of pions, kaons, protons and anti-protons in Au+Au collisions at 130 GeV [2] [pub1-2], 200 GeV [talk15-16] [proc1,9] [pub3], and 62 GeV [pub7]. These measurements are partially supported by this grant. As an example, Figure 1 shows the pions, kaons, and (anti-proton) spectra in Au+Au collisions at 200 GeV [talk15-16] [proc1] [pub3].

The measured identified particle ratios yielded a chemical freeze-out temperature of  $157 \pm 6$  MeV [pub3],

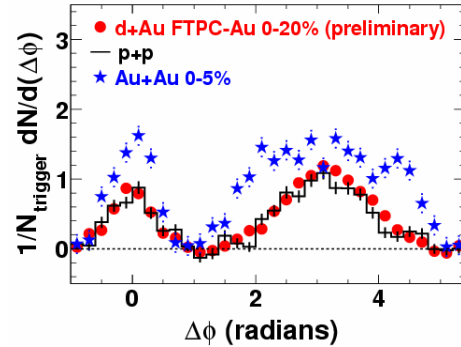
approximately coinciding with the predicted phase transition temperature from lattice QCD. The measured identified hadron distributions are well described by hydrodynamics, yielding a decreasing kinetic freeze-out temperature and an increasing transverse radial flow velocity as a function of the collision centrality, reaching the values of  $89 \pm 10$  MeV and  $(0.59 \pm 0.05)c$ , respectively, for the most central collisions [pub3]. The drop in the temperature and the development of strong radial flow suggest a significant expansion and long duration from chemical freeze-out to kinetic freeze-out.

The measured chemical freeze-out condition from particle yields at 130 and 200 GeV is insensitive to the various initial conditions, with a universal chemical freeze-out temperature. This is shown in Figure 2. The chemical freeze-out temperature coincides with the QCD predicted phase transition (hadronization) temperature, which indeed should be universal. The kinetic spectra of rare particles ( $\Phi, \Xi, \Omega$ ) indicate a kinetic freeze-out temperature of about 160 MeV, implying that they decouple from the system right after chemical freeze-out. They carry a flow velocity of  $0.4c$ . The more common particles ( $\pi, K, K^*, p, \Lambda$ ), due to their large interaction cross-sections, undergo further cooling and expansion from chemical freeze-out to kinetic freeze-out. This effect is the strongest in central collision with a kinetic freeze-out temperature of about 90 MeV and expansion velocity of approximately  $0.6c$ . In summary, Au+Au collisions of various centralities, despite of the different initial conditions, always evolve to the same chemical freeze-out condition, likely hadronization or phase transition, followed by a further cooling and expansion towards final kinetic freeze-out.

## 2.2 Measurements of Jet-Correlations

Jets from hard-scattered partons provide an “external”, penetrating probe into the hot and dense medium created in relativistic heavy-ion collisions, because they traverse and interact with the created medium. The away side jet partner is significantly depleted at large  $p_T$  [3]. The depleted energy must be redistributed to low  $p_T$  particles. Reconstruction of these low  $p_T$  particles will provide powerful tool to study the medium properties. We have pioneered the technique of statistical reconstruction of jets of charged hadrons by subtracting combinatorial background and use modification to jet correlations to study the properties of the medium created in heavy-ion collisions [talk2-6,17-18] [proc2-6] [pub4].

Figure 3 shows the background subtracted  $\Delta\phi$  correlations in  $pp$ , d+Au, and central Au+Au collisions [pub4] [talk5-6] [proc5-6]. On the near side ( $|\Delta\phi| < 1.0$ ), correlation structures typical of jets are observed in  $pp$  and Au+Au collisions. On the away side ( $|\Delta\phi| > 1.0$ ), the correlation is broader and stronger in central Au+Au than in  $pp$  and d+Au collisions.



**Figure 3.** Background subtracted  $\Delta\phi$  correlations between leading trigger particles of  $4 < p_{T}^{\text{trig}} < 6$  GeV/c and associated hadrons of  $0.15 < p_T < 4$  GeV/c from STAR [pub4] [talk5-6] [proc5-6].

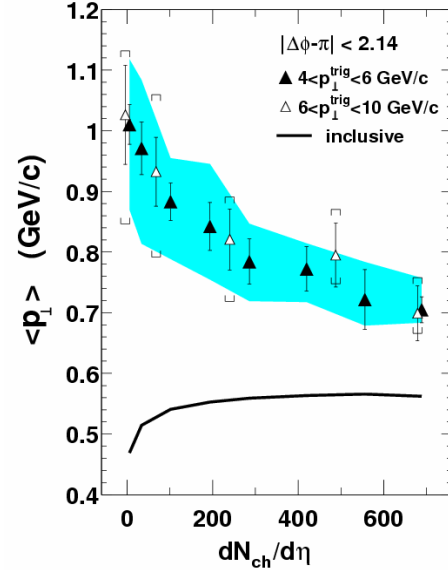
The associated hadron  $p_T$  distributions were extracted from the correlation functions [pub4]. The near-side spectral shapes are similar within errors for p+p and Au+Au of all centralities. The away-side spectrum is significantly softened in central Au+Au collisions compared to those in p+p and peripheral Au+Au.

Figure 4 shows the centrality dependence of  $\langle p_T \rangle$  of the away side associated particles [pub4]. Also shown by the line are the  $\langle p_T \rangle$  of inclusive hadron which increases with centrality due to collective radial flow. The associated particle  $\langle p_T \rangle$ , while significantly larger than that of inclusive hadrons in pp and peripheral Au+Au collisions, drops rapidly with centrality in Au+Au collisions, approaching the inclusive hadron  $\langle p_T \rangle$ . The results may indicate a progressive equilibration of the associated hadrons with the bulk medium from peripheral to central collisions.

It was further shown that the away side hadrons more collimated at  $180^\circ$  from the trigger particle have smaller average  $p_T$  than those less collimated in central collisions [talk5-6] [proc5-6]. This is the opposite of what one would expect from jet-like behavior, and is consistent with pathlength dependent jet-medium interaction.

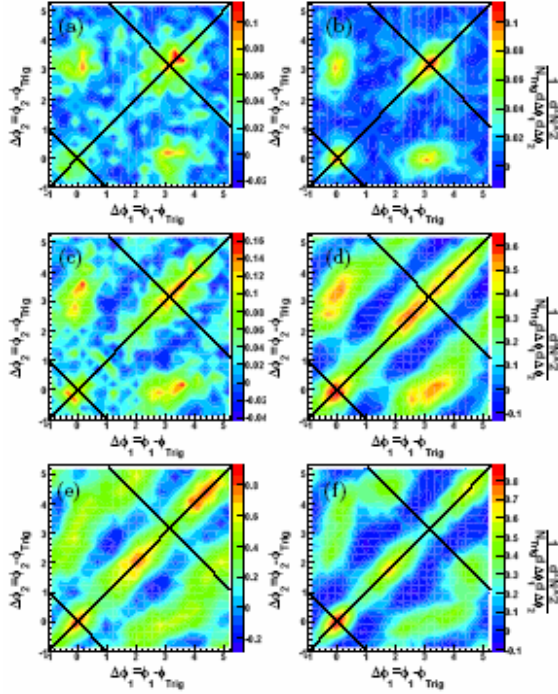
We have also studied jet-correlations with identified trigger particles. This is to shed more light on the baryon/meson puzzle at RHIC where a significantly larger baryon/meson ratio is observed at intermediate  $p_T$  in central Au+Au collisions than in pp collisions. The large ratio suggests that not all those baryons come from hard-scattered partons. To verify or refute this conjecture, we carried out the analysis of jet correlations with high  $p_T$  pions and (anti-)protons [talk19,21] [proc8]. We identify high  $p_T$  particles by their relativistic rise of specific energy loss in the STAR-TPC. We observed practically no difference between the angular correlations with leading pions and (anti-)protons, suggesting that all baryons originated from parton-parton hard-scattering similar to mesons. Therefore the large increase in (anti-)proton production relative to pion must be intrinsic to the medium created in heavy-ion collisions.

The away-side correlated hadrons and energies were observed to be broadly distributed and possess structures that are no longer jet-like. A number of possible physics mechanisms can account for the observation. One exciting possibility is the conical flow, induced by the energy deposited by the away-side jet that disturbs the medium producing Mach-cone-like effect [4,5,6,7]. If the conical flow is indeed the underlying mechanism, far-reaching conclusions may be drawn: the medium must be close to a thermalized, hydrodynamic-like system, the speed of sound can be deduced from the measured Mach-cone angle, and the equation of state of the medium can be inferred. While these different scenarios produce the same two-particle angular

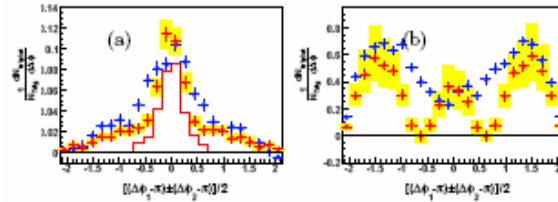


**Figure 4.** Away side associated charged hadron  $\langle p_T \rangle$  for  $4 < p_T^{trig} < 6$  GeV/c (systematic errors in band) and  $6 < p_T^{trig} < 10$  GeV/c (systematic errors in caps). The leftmost set of data are for pp. Some of the open points are slightly displaced in  $dN_{ch}/d\eta$  for clarity. Figure from [pub4].

correlations, they give rise to different three-particle angular correlation patterns. Thus three-particle correlations offer the decisive means to identify the underlying physics mechanisms responsible for the broad away-side correlations.



**Figure 5.** Background subtracted 3-particle azimuthal correlations in (a)  $pp$ , (b)  $d+Au$ , (c) 80-50%  $Au+Au$ , (d) 50-30%  $Au+Au$ , (e) 30-10%  $Au+Au$ , and (f) ZDC-trigger 12% central  $Au+Au$  collisions.



**Figure 6.** Diagonal (blue) and off-diagonal (red) projections of away-side 3-particle correlations in (a)  $d+Au$  and (b) ZDC-trigger 12% central  $Au+Au$  collisions. The histogram in (a) is the near-side off-diagonal projection.

the near-side jet, but has a large acoplanarity due to  $k_T$  broadening from initial parton scattering.

For central  $Au+Au$  collisions, additional structures are observed on the away side along the off-diagonal. Figure 8(b) shows the diagonal and off-diagonal projections of the away-side 3-particle correlation result from the ZDC data. The off-diagonal side peaks are prominent. These peaks are consistent with conical emission of correlated particles. The side peaks in the diagonal projection contain conical emission as well as other contributions. The diagonal projection, with conical emission peaks removed, is quite

We carried out the seminal analysis of 3-particle azimuthal jet-like correlations [talk8-9,11-14,19-24] [proc8,10-15]. The major challenge in this analysis is the subtraction of background. The method of background subtraction is described in detail in [pub5]. Figure 5 shows the background subtracted 3-particle correlations in minimum bias  $pp$ ,  $d+Au$ , and three combined centralities of minimum bias  $Au+Au$  and the ZDC-trigger 12% central  $Au+Au$  collisions. Four distinctive peak areas are observed, corresponding to the two associated particles to be both on the same side of the trigger around  $\Delta\phi_1=\Delta\phi_2=0$  (near-side), both on the opposite side around  $\pi$  (away-side), and one on each side (near-away). The near-side peak is elongated along the diagonal in  $d+Au$  and  $Au+Au$  collisions, likely due to effect caused by the trigger direction being not as same as the jet thrust axis.

The away-side central peak is significantly elongated along the diagonal from  $pp$  to  $d+Au$  to  $Au+Au$  collisions. Figure 7(a) shows the effect quantitatively by projecting the  $d+Au$  3-particle correlation on the away side ( $1 < \Delta\phi_{1,2} < 2\pi$ ) along the diagonal and off-diagonal, respectively. For comparison the off-diagonal projection on the near side ( $|\Delta\phi_{1,2}| < 1$ ) is also shown (solid histogram). The results indicate that the away-side jet is as narrowly clustered as

broad and could be a net effect of  $k_T$  broadening, large angle gluon radiation, and deflected jets.

The angular distance the off-diagonal peak locations from  $\pi$  are obtained by fitting the off-diagonal projections to a central plus two symmetric side Gaussians. For ZDC data, the angle is about 1.4 radians. If the observed conical emission is generated by Mach-cone shock waves, the measured angle reflects the speed of sound of the created medium averaged over the evolution of the collision history.

### 3. Ph.D. Degrees, Presentations and Publications

#### Ph.D. Degrees:

Two Ph.D. students were trained with the support of the grant:

Levente Molnar

Entered graduate school: Aug. 2000

Joined group: Aug. 2002

Mentor: Fuqiang Wang

Ph.D. granted: July 2006

Thesis title: *Systematics of Identified Particle Production in pp, d-Au and Au-Au Collisions at RHIC Energies*

Current employment: Postdoctoral fellow, INFN Sezione di Bari, Italy.

Jason Ulery

Entered graduate school: Aug. 2000

Joined group: Aug. 2002

Mentor: Fuqiang Wang

Ph.D. to be granted: December 2007

Thesis title: *Two- and Three-Particle Jet-Like Correlations*

Current employment (starting spring 2008): Postdoctoral fellow, Frankfurt University, Germany.

#### Invited talks:

- [talk1] BULK PROPERTIES OF THE COLLISION AT RHIC, Fuqiang Wang, *DNP Fall meeting*, University of Arizona, Tuscon, Arizona, November, 2003.
- [talk2] MEASUREMENT OF JET MODIFICATION AT RHIC, Fuqiang Wang, *20<sup>th</sup> Winter Workshop on Nuclear Dynamics*, Trelawny Beach, Jamaica, March 15-20, 2004.
- [talk3] MEASUREMENT OF JET MODIFICATION AT RHIC, Fuqiang Wang, *Rencontres de Moriond - The XXXIXth Rencontres de Moriond session devoted to QCD and High Energy Hadronic Interactions*, La Thuile, Aosta valley, Italy, March 28 - April 4, 2004.
- [talk4] STAR MEASUREMENT OF JET MODIFICATION IN AU+AU COLLISIONS, Fuqiang Wang, *RHIC & AGS Annual Users' Meeting Workshop "Jets,  $jT$ ,  $kT$ "*, BNL, New York, May 11, 2004.
- [talk5] DISTRIBUTIONS OF CHARGED HADRONS ASSOCIATED WITH HIGH PT PARTICLES, Fuqiang Wang, *Riken BNL Research Center Workshop "Jet Correlations at RHIC"*, BNL, New York, March 10-11, 2005.



- [talk6] DISTRIBUTIONS OF CHARGED HADRONS ASSOCIATED WITH HIGH PT PARTICLES, Fuqiang Wang, *MIT Workshop on "Correlations and Fluctuations in Relativistic Nuclear Collisions"*, MIT, Cambridge, Massachusetts, April 21-23, 2005.
- [talk7] SOFT PHYSICS FROM STAR, Fuqiang Wang (for STAR Collaboration), *the 18th International Conference on Ultrarelativistic Nucleus-Nucleus Collisions: Quark Matter 2005 (QM 2005)*, Budapest, Hungary, August 4-9, 2005.
- [talk8] NEW DEVELOPMENTS FROM STAR, Jason Ulery, *AGS/RHIC Users Meeting Workshop on "Interactions between Hard Probes and the Bulk"*, BNL, NY, June 2006.
- [talk9] SUPERSONIC JETS IN RELATIVISTIC HEAVY-ION COLLISIONS, Fuqiang Wang, *Quark Confinement and the Hadron Spectrum 7*, Ponta Delgada, Azores, Portugal, September 2-7, 2006.
- [talk10] JET ENERGY LOSS AND CORRELATIONS FROM STAR, Fuqiang Wang (for the STAR Collaboration), *Pre-Meeting Workshop: Properties and Signatures of sQGP 2006 Division of Nuclear Physics Annual Meeting*, Nashville, Tennessee, October 25, 2006.
- [talk11] IN-MEDIUM PROPERTIES OF JETS, Fuqiang Wang, *the 19th International Conference on Ultrarelativistic Nucleus-Nucleus Collisions: Quark Matter 2005 (QM 2005)*, Shanghai, China, November 14-20, 2006.
- [talk12] THREE-PARTICLE CORRELATIONS FROM STAR, Jason Ulery, *XIth International Workshop on Correlation and Fluctuation in Multiparticle Production*, Hangzhou, China, November 2006.
- [talk13] THREE-PARTICLE AZIMUTHAL CORRELATIONS, Jason Ulery, *High- $p_T$  Physics at the LHC*, Jyväskylä, Finland, March 2007.
- [talk14] THREE-PARTICLE CORRELATIONS AT RHIC, Jason Ulery, *37<sup>th</sup> International Symposium on Multiparticle Dynamics*, Berkeley, California, August 2007.

### **Contributed Talks:**

- [talk15] MID-RAPIDITY PION, KAON AND ANTIPROTON YIELDS AND SPECTRA IN AU+AU COLLISION AT 130 AND 200 GEV FROM STAR, Fuqiang Wang (for STAR Collaboration), *Quark Matter 2002: 16<sup>th</sup> International Conference on Ultra-Relativistic Nucleus-Nucleus Collisions*, Nantes, France, July 18-24, 2002.
- [talk16] IDENTIFIED PARTICLE SPECTRA AND MULTIPLICITY DEPENDENCE IN P+P AND D+AU COLLISIONS IN STAR, Levente Molnar (for the STAR Collaboration), *DNP Fall meeting*, University of Arizona, Tucson, Arizona, Oct. 29 - Nov. 1, 2003.
- [talk17] MEASUREMENT OF JET FRAGMENTATION AT RHIC, Fuqiang Wang (for STAR Collaboration), *Quark Matter 2004: 17<sup>th</sup> International Conference on Ultra-Relativistic Nucleus-Nucleus Collisions*, Oakland, California, January 11-17, 2004.
- [talk18] STATISTICAL JET RECONSTRUCTION IN D+AU COLLISIONS AT STAR, Jason Ulery (for the STAR Collaboration), *Division of Nuclear Physics 2004 Fall Meeting*, Chicago, Illinois, October 2004.
- [talk19] FULL RECONSTRUCTION OF  $h^\pm$  CORRELATED WITH HIGH PT  $h^\pm$  AND IDENTIFIED BARYONS AND MESONS FROM STAR, Jason Ulery (for STAR Collaboration), *the 18th International Conference on Ultrarelativistic Nucleus-Nucleus Collisions: Quark Matter 2005 (QM 2005)*, Budapest, Hungary, August 4-9, 2005.
- [talk20] THREE-PARTICLE CORRELATIONS, Jason Ulery (for the STAR Collaboration), *Midwest Critical Mass Conference*, Toledo, Ohio, October 2005.
- [talk21] FULL RECONSTRUCTION OF CHARGED HADRONS CORRELATED WITH HIGH PT  $h^\pm$  AND IDENTIFIED BARYONS AND MESONS FROM STAR, Jason Ulery (for the STAR Collaboration), *Physics of the Early Universe Conference OSAPS Spring 2006 Meeting*, Detroit, Michigan, April 2006.

- [talk22] THREE-PARTICLE AZIMUTHAL CORRELATIONS FROM STAR, Jason Ulery (for the STAR Collaboration), *2<sup>nd</sup> International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions*, Pacific Grove, California, June 2006.
- [talk23] THREE-PARTICLE AZIMUTHAL CORRELATIONS FROM STAR, Jason Ulery (for the STAR Collaboration), *18<sup>th</sup> Annual Nuclear Physics Summer School*, Bloomington, Indiana, August 2006.
- [talk24] THREE-PARTICLE AZIMUTHAL CORRELATIONS FROM STAR, Jason Ulery (for the STAR Collaboration), *School of Collective Dynamics in High Energy Collisions*, Berkeley, California, May 2007.

### **Conference Proceedings:**

- [proc1] MID-RAPIDITY  $\pi^{+-}$ ,  $K^{+-}$  AND ANTI-P SPECTRA AND PARTICLE RATIOS FROM STAR, *In proceedings of Quark Matter 2002*, O. Barannikova and F. Wang (STAR Collaboration), Nucl. Phys. **A715** (2003) 458c-461c [nucl-ex/0210034].
- [proc2] MEASUREMENT OF JET MODIFICATION AT RHIC, Fuqiang Wang (for STAR Collaboration), *In Proceedings of Quark Matter 2004*, J. Phys. G: Nucl. Part. Phys **30** (2004) S1299 [nucl-ex/0404010].
- [proc3] MEASUREMENT OF JET MODIFICATION AT RHIC, Fuqiang Wang, *in proceedings of XXXIXth Rencontres de Moriond – QCD AND HIGH ENERGY HADRONIC INTERACTION*, ed. Etienne Auge and J. Tran Thanh Van, 2004, pp. 317.
- [proc4] MEASUREMENT OF JET MODIFICATION AT RHIC, Fuqiang Wang, *in proceedings of the 20<sup>th</sup> Winter Workshop on Nuclear Dynamics*, Acta Phys. Hung. A24 (2005) 299-306.
- [proc5] DISTRIBUTIONS OF CHARGED HADRONS ASSOCIATED WITH HIGH PT PARTICLES, Fuqiang Wang (for STAR Collaboration), *in proceedings of Riken BNL Research Center Workshop on “Jet Correlations at RHIC”*. BNL, New York, March 10-11, 2005.
- [proc6] DISTRIBUTIONS OF CHARGED HADRONS ASSOCIATED WITH HIGH PT PARTICLES, Fuqiang Wang (for STAR Collaboration), *in proceedings of MIT Workshop on "Correlations and Fluctuations in Relativistic Nuclear Collisions"*, J. Phys. Conf. Ser. 27, 32-41 (2005), e-print archive: nucl-ex/0508021.
- [proc7] SOFT PHYSICS FROM STAR, Fuqiang Wang (for STAR Collaboration), *in proceedings of the 18th International Conference on Ultrarelativistic Nucleus-Nucleus Collisions: Quark Matter 2005 (QM 2005)*, Nucl. Phys. **A774**, 129-138 (2006), eprint archive: nucl-ex/0510068.
- [proc8] TWO- AND THREE-PARTICLE JET CORRELATIONS FROM STAR, Jason Ulery (for STAR Collaboration), *in proceedings of “the 18th International Conference on Ultrarelativistic Nucleus-Nucleus Collisions: Quark Matter 2005 (QM 2005)”*, Nucl. Phys. **A774**, 581-584 (2006), E-print arXiv: nucl-ex/0510055.
- [proc9] EFFECT OF RESONANCE DECAYS ON EXTRACTED KINETIC FREEZE-OUT PARAMETERS IN HEAVY ION COLLISIONS AT RHIC, L. Molnar, O. Barannikova, and F. Wang, *the 18th International Conference on Ultrarelativistic Nucleus-Nucleus Collisions: Quark Matter 2005 (QM 2005)*, Rom. Rep. Phys. **58**, 19 (2006).
- [proc10] THREE-PARTICLE AZIMUTHAL CORRELATIONS, Jason Ulery (for the STAR Collaboration), Nucl. Phys. **A783** (2007) 511-514, arXiv: nucl-ex/0609047. *In Proceedings of Hard Probes 2006*.
- [proc11] SUPERSONIC JETS IN RELATIVISTIC HEAVY-ION COLLISIONS, Fuqiang Wang, *in the proceedings of Quark Confinement and the Hadron Spectrum 7*. AIP Conf. Proc. **892**, 417-420 (2007). e-Print Archive: nucl-ex/0610027.

- [proc12] IN-MEDIUM PROPERTIES OF JETS, Fuqiang Wang (for STAR Collaboration), in *proceedings of the 19th International Conference on Ultrarelativistic Nucleus-Nucleus Collisions: Quark Matter 2006 (QM 2006)*, J. Phys. G **34**, S337-S344 (2007), e-Print arXiv:0707.0801 [nucl-ex].
- [proc13] ARE THERE MACH CONES IN HEAVY ION COLLISIONS? THREE-PARTICLE CORRELATIONS FROM STAR, Jason Ulery (for the STAR Collaboration), arXiv:0704.0224. In *proceedings of Quark Matter 2006*.
- [proc14] THREE PARTICLE CORRELATIONS FROM STAR, Jason Ulery (for the STAR Collaboration), arXiv:0704.0220. In *proceedings of IWCF 2006*.
- [proc15] THREE-PARTICLE AZIMUTHAL CORRELATIONS, Jason Ulery, arXiv:0709.1633. In *proceedings of High  $p_T$  physics at the LHC*.

### **Refereed Journal Publications:**

- [pub1] KAON PRODUCTION AND KAON TO PION RATIO IN AU + AU COLLISIONS AT  $\sqrt{s_{NN}} = 130$  GEV, C. Adler, *et al.* (STAR Collaboration), Phys. Lett. B **595** (2004) 143-150.
- [pub2] RAPIDITY AND CENTRALITY DEPENDENCE OF PROTON AND ANTI-PROTON PRODUCTION FROM AU+AU COLLISIONS AT  $\sqrt{s_{NN}} = 130$  GeV, J. Adams *et al.* (STAR Collaboration), Phys. Rev. C **70**, 041901 (2004).
- [pub3] IDENTIFIED PARTICLE DISTRIBUTIONS IN PP AND AU+AU COLLISIONS AT  $\sqrt{s_{NN}} = 200$  GeV, J. Adams, *et al.* (STAR Collaboration), Phys. Rev. Lett. **92**, 112301 (2004).
- [pub4] DISTRIBUTIONS OF CHARGED HADRONS ASSOCIATED WITH HIGH TRANSVERSE MOMENTUM PARTICLES IN PP AND AU+AU COLLISIONS AT  $\sqrt{s_{NN}} = 200$  GEV, J. Adams, *et al.* (STAR Collaboration), Phys. Rev. Lett. **95** (2005) 152301.
- [pub5] ANALYSIS METHOD FOR JET-LIKE THREE-PARTICLE AZIMUTHAL CORRELATIONS, Jason G. Ulery and Fuqiang Wang, e-Print Archive: nucl-ex/0609016.
- [pub6] THREE-PARTICLE CUMULANT VERSUS THREE-PARTICLE JET-LIKE CORRELATION, Jason G. Ulery and Fuqiang Wang, e-Print Archive: nucl-ex/0609017.
- [pub7] SYSTEMATIC MEASUREMENTS OF IDENTIFIED PARTICLE SPECTRA IN PP, D+AU AND AU+AU COLLISIONS FROM STAR, B.I. Abelev, *et al.* (STAR Collaboration), in preparation.

### **REFERENCES**

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- <sup>1</sup> F. Karsch, Nucl. Phys. **A698**, 199c (2002).
- <sup>2</sup> C. Adler *et al.* (STAR Collaboration), Phys. Rev. Lett. **87** (2001) 262302.
- <sup>3</sup> C. Adler *et al.* (STAR), Phys. Rev. Lett. **90**, 082302 (2003).
- <sup>4</sup> H. Stoecker, Nucl. Phys. **A750**, 121 (2005).
- <sup>5</sup> J. Casalderrey-Solana, E. Shuryak and D. Teaney, J. Phys. Conf. Ser. **27**, 23 (2005).
- <sup>6</sup> J. Ruppert and B. Muller, Phys. Lett. B **618**, 123 (2005).
- <sup>7</sup> T. Renk and J. Ruppert, Phys. Rev. C **73**, 011901 (2006).