|  |
| --- |
| PHYSICS 224CNuclear Physics III - Experimental High Energy |

## You can find this page at <http://nuclear.ucdavis.edu/~cebra/classes/phys224/phys224c.html>

## QUARTER: Fall 2008 LECTURES: 432 Phys/Geo, TR 1:10 to 2:30 INSTRUCTOR: Daniel Cebra, 539 P/G, 752-4592, cebra@physics.ucdavis.edu GRADERS: none

**TEXT:** **No required text. The following could be useful:**

R.L Vogt Ultrarelativistic Heavy Ion Collisions

C.Y. Wong Introduction to High-Energy Heavy-Ion Collisions  
L.P. Csernai Introduction to Relativistic Heavy Ion Collisions  
J. Letessier and J. Rafelski Hadrons and Quark-Gluon Plasma

**HOMEWORK: There will be presentations assigned through the quarter.   
  
EXAM:  There will be no exams for this course  
  
GRADE DETERMINATION: Grade will be determined presentations and class participation  
  
OFFICE HOURS: Cebra (any time)**

**Course Overview:** The class will be taught as a seminar class. We will alternate between lectures to overview the concepts with readings and discussions of critical papers in the field. There will be no homework assignments, no exams. Students are read the discussion papers ahead and to come prepared for presentations.

Class Outline: The Class will follow the evolution of a relativistic heavy ion collision:

1. Overview and Historical Perspective
   1. Hagedorn Bootstrap Model
   2. Bjorken energy density
   3. Basic Kinematics
2. Quantum Chromodynamics
   1. Asymptotic freedom
   2. Confinement
   3. Chirality
3. Initial Conditions and First Collisions
   1. Glauber Model --- pre-collision and initial geometry (impact parameter)
   2. Color-Glass Condensate
   3. Parton Cascade ---
4. Quark-Gluon Plasma Formation and Evolution
   1. Lattice QCD
   2. Hydrodynamics
   3. Elliptic flow
5. Probes of the Dense Partonic Phase
   1. J/ Suppression and open charm
   2. Jets
   3. Direct Photons
   4. Di-Leptons
6. Hadronization
   1. Recombination vs. Fragmentation
   2. Chemical Equilibrium, Chemical freeze-out
   3. Strangeness enhancement
7. Thermal Freeze-out
   1. Pion production/Entropy
   2. Radial Flow
   3. HBT
8. Accelerators and Detector for Heavy-Ion Physics
9. Implications
   1. Big Bang Cosmology
   2. BBN
   3. Supernovae
   4. Neutron, Strange, and Quark Stars

**Readings/References**

**TOPIC I: General Overview and Introduction to Relativistic Heavy Ion Physics**

Chapter 1 of F. Halzen and A. Martin *Quarks and Leptons*   
Chapter 6 of Perkins and/or any other introduction to QCD  
Chapter 2 of Wong *kinematic variables*

Statistical Thermodynamics of Strong Interactions at high Energies

R*.* Hagedorn*, Suppl.* Nuovo *Cimento 3, 147, 1965*

*Very High Energy Collisions of Hadrons*  
[R.P. Feynman, Phys. Rev. Lett. 23, 1415 (1969)](http://link.aps.org/ejnls/volpage/?journal_code=PRL&volume=23&issue=&pageno=1415&mail_error=prltech@aps.org)

*Highly Relativistic Nucleus-Nucleus Collisions: The Central Rapidity Region*  
[J. D. Bjorken, Phys. Rev. D27, 140 (1983)](http://prola.aps.org/abstract/PRD/v27/i1/p140_1)

*Lectures given by R. Bellwied at Graduate Summer School, Germany 2004* [1](http://rhic.physics.wayne.edu/%7Ebellwied/ppt/rauisch-1.ppt),[2](http://rhic.physics.wayne.edu/%7Ebellwied/ppt/rauisch-2.ppt),[3](http://rhic.physics.wayne.edu/%7Ebellwied/ppt/rauisch-3.ppt)

*Lectures given by John Harris at Winter Institute, Lake Louise, 2006* [1](http://rhic.physics.wayne.edu/%7Ebellwied/phy8800/ll-w1.ppt), [2](http://rhic.physics.wayne.edu/%7Ebellwied/phy8800/ll-w2.ppt)

*The STAR Whitepaper* [nucl-ex/0501009](http://xxx.lanl.gov/abs/nucl-ex/0501009)

*The PHENIX Whitepaper* [nucl-ex/0410003](http://xxx.lanl.gov/abs/nucl-ex/0410003)

*CORE - COmpendium on RElations* [hep-ph/9507456](http://xxx.lanl.gov/abs/hep-ph/9507456)

*The Physics of Thermal QCD* [Smilga, hep-ph/9612347](http://xxx.lanl.gov/abs/hep-ph/9612347)

**TOPIC II: Quantum Chromodynamics**

Reading assignment for this lesson

*Lecture on foundation in QCD* [Smilga, hep-ph/9901412](http://xxx.lanl.gov/abs/hep-ph/9901412)

*Asymptotic Freedom and QCD*  
[Nobel Prize Lecture, Frank Wilczek, hep-ph/0502113](http://xxx.lanl.gov/abs/hep-ph/0502113)

*Gribov's lectures on confinement*  
[Lecture 1, hep-ph/9403218](http://xxx.lanl.gov/abs/hep-ph/9403218)  
[Lecture 2, hep-ph/9404332](http://xxx.lanl.gov/abs/hep-ph/9404332)

*Why is a nucleon bound ?*  
[Ed Shuryak, hep-ph/9603354](http://xxx.lanl.gov/abs/hep-ph/9603354)

*Chiral Symmetry Restoration*  
[Volker Koch, nucl-th/9706075](http://xxx.lanl.gov/abs/nucl-th/9706075)

**TOPIC III: Initial Conditions and First Collisions**

Reading assignment for this lesson

*Glauber Model in RHI collisions* [nucl-ex/0701025](http://xxx.lanl.gov/abs/nucl-ex/0701025)

*The Color Glass Condensate: an Introduction*[*E. Iancu et al.,hep-ph/0202270*](http://xxx.lanl.gov/abs/hep-ph/0202270)

*Comment: The important concepts are in the first part of the article, but a more ambitious reader should go on farther.*

**TOPIC IV: Quark-Gluon Plasma Formation and Evolution**

Reading assignment for this lesson

*Phase Transitions in QCD*  
[H.Meyer-Ortmanns, hep-lat/9608098](http://xxx.lanl.gov/abs/hep-lat/9608098)

*Introduction to Lattice QCD*  
[Rajan Gupta, hep-lat/9807028](http://xxx.lanl.gov/abs/hep-lat/9807028)

*Comment: Read only sections 1-10. A long but introductory article. Read what you can for a first impression; but you will not be able to understand everything. Take down questions for class.*

*Recent lattice Results Relevant for Heavy Ion Collisions*[*Kazauyuki Kanaya, hep-ph/0209116*](http://xxx.lanl.gov/abs/hep-ph/0209116)

*Comment: Short and should be of interest to students who work on RHIC physics. This will be discussed in more detail in class, so read and try to understand and mark down questions.*

*Hydrodynamical models (I)* [nucl-th/0404039](http://xxx.lanl.gov/abs/nucl-th/0404039)

*Hydrodynamical models (II)* [nucl-th/0410017](http://xxx.lanl.gov/abs/nucl-th/0410017)

*Hydrodynamical models (III)* [Recent summary by Ruuskanen and Eskola, nucl-th/0605008](http://xxx.lanl.gov/abs/nucl-th/0605008)

**TOPIC V: Probes of the Dense Partonic Phase**

Reading assignment for this lesson

*Space-time Structure of Initial Parton Production in Ultrarelativistic Heavy Ion Collisions*,  
[K.J. Eskola and X.N. Wang, Phys. Rev. D, preprint LBL-34156](http://prola.aps.org/abstract/PRD/v49/i3/p1284_1?qid=f2e740ac3add0dd2&qseq=3&show=10)

*Jets in Relativistic Heavy Ion Collisions*  
[X.N. Wang and M. Gyulassy, preprint LBL-29390](http://star.physics.yale.edu/%7Eharris/physics_671a/Jets.pdf)

*GLV approach to radiative energy loss* [Gyulassy et al., hep-ph/9907461](http://xxx.lanl.gov/abs/hep-ph/9907461)

*BDMPS approach to radiative energy loss* [Baier et al., hep-ph/9607355](http://xxx.lanl.gov/abs/hep-ph/9607355)

*LPM effect in QED* [Baier et al., hep-ph/9604327](http://xxx.lanl.gov/abs/hep-ph/9604327)

*Energy Loss in High Energy Heavy Ion Collisions from the Hydro + Jet*  
[T. Hirano and Y. Nara, hep-ph/0208029](http://www.slac.stanford.edu/spires/find/hep/www?AUTHOR=&TITLE=&C=&REPORT-NUM=&AFFILIATION=&cn=&k=&cc=&eprint=HEP-PH&eprint=0208029&topcit=&url=&J=+&*=&ps=+&DATE=&*=+&FORMAT=WWW&SEQUENCE=)

*Summary of Status of RHIC data (II),*[*P. Jacobs and X.N. Wang*](http://xxx.lanl.gov/abs/hep-ph/0405125)

*High pt probes,*[*P. Jacobs*](http://xxx.lanl.gov/abs/nucl-ex/0503022)

*High pT Azimuthal Asymmetry in Non-central A+A at RHIC*[*STAR collaboration, PRL 90 (2003)*](http://star.physics.yale.edu/%7Eharris/physics_671a/0206006.pdf)

*High pt Tomography of d+Au and Au+Au at SPS, RHIC and LHC*[*X.N.Wang, I. Vitev, M.Gyulassy, PRL 86 (2001)*](http://star.physics.yale.edu/%7Eharris/physics_671a/0012092.pdf)

*Gluon Shadowing and Jet Quenching in A+A Collisions at sqrt(s)=200A GeV*[*X.N.Wang, M.Gyulassy, PRL 68 (1992)*](http://cornell.mirror.aps.org/abstract/PRL/v68/i10/p1480_1)

*Heavy Quarks and QCD Matter*[*D. Kharzeev, Nucl.Phys.A702 (2002)*](http://xxx.lanl.gov/abs/hep-ph/0111386)

*Charmonium Suppression*[*Matsui and Satz,Phys. Lett. B 178 (1986) 416.*](http://star.physics.yale.edu/%7Eharris/physics_671a/matsui.pdf)

*Charmonium Suppression (experimental),*[*NA50 Collaboration, Phys. Lett. B 450 (1999) 456.*](http://star.physics.yale.edu/%7Eharris/physics_671a/na50.pdf)

*Heavy Flavor Energy Loss*[*M. Djordjevic, hep-ph/0410372*](http://xxx.lanl.gov/abs/hep-ph/0410372)

**TOPIC VI: Hadronization**

Reading assignment for this lesson

*Hadron Production in Au-Au Collisions at RHIC*  
[P. Braun-Munzinger, D. Magestro, K. Redlich, and J. Stachel, hep-ph/0105229](http://xxx.lanl.gov/abs/hep-ph/0105229)

*Thermal Phenomenology of Hadrons from 200 A GeV S + S Collisions*  
[E. Schnedermann, J. Sollfrank, and U. Heinz, Nucl-th/9307020](http://xxx.lanl.gov/abs/nucl-th/9307020)

*Chemical Equilibration in Pb + Pb Collisions at the SPS*  
[P. Braun-Munzinger, I. Heppe, and J. Stachel, nucl-th/9903010v2](http://xxx.lanl.gov/abs/nucl-th/9903010v2)

*Chemical Equilibration and the Hadron-QGP Phase Transition*  
[P. Braun-Munzinger, nucl-ex/0007021](http://xxx.lanl.gov/abs/nucl-ex/0007021)

*Strangeness Production in the Quark-Gluon Plasma*[*Rafelski et al., Phys. Rev. Letter 48, (1982) 12066*](http://star.physics.yale.edu/%7Eharris/physics_671a/PhysRevLett48_1066.pdf)[*Rafelski et al., Phys. Rev. Letter 56, 2334*](http://star.physics.yale.edu/%7Eharris/physics_671a/PhysRevLett56_2334.pdf)*.*

*Strangeness Production in Heavy Ion Collisions*[*Redlich et al., Nuc. Phys. A698 (2002) 94c*](http://star.physics.yale.edu/%7Eharris/physics_671a/NuclPhysA698_94.pdf)*.*

*Resonance Production in medium*[*C. Markert, nucl-ex/0503013*](http://xxx.lanl.gov/abs/nucl-ex/0503013)

**Topic VII: Thermal Freeze-out**

*Reading assignment for this lesson*

*Year-1 data from RHIC*[*J. Nagle and T. Ullrich, nucl-ex/0203007*](http://xxx.lanl.gov/abs/nucl-ex/0203007)

*Early Bulk Data Summary*[*T. Ullrich, nucl-ex/0211004*](http://xxx.lanl.gov/abs/nucl-ex/0211004)

*Summary of Status of RHIC data (I)*[*B. Mueller and J.Nagle, nucl-th/0602029*](http://xxx.lanl.gov/abs/nucl-th/0602029)

*Femtoscopy*[*M. Lisa et al., nucl-ex/0505014*](http://xxx.lanl.gov/abs/nucl-ex/0505014)

**TOPIC VIII: Implications**

*Reading assignment for this lesson*

**Other Relevant Papers**

*Supersymmetric string models in RHIC physics*[*Policastro, Son and Starinets,hep-th/0104066*](http://xxx.lanl.gov/abs/hep-th/0104066)

*Supersymmetric string models in RHIC physics (II)*[*Kovtun, Son and Starinets,hep-th/0405231*](http://xxx.lanl.gov/abs/hep-th/0405231)

*CGC+hydro+strings*[*T.Hirano and Y.Nara,nucl-th/0404039/*](http://xxx.lanl.gov/abs/nucl-th/0404039)

*From pions to pentaquarks*  
[Dmitri Diakonov, hep-ph/0406043](http://xxx.lanl.gov/abs/hep-ph/0406043)