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Results from PHENIX: Year-1 and Outlook

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Abstract. The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory had its first phsyics run Summer 2000 colliding Au+Au ions at $\sqrt{s_{NN}} = 130\text{GeV}$ energy. The PHENIX experiment measured global observables of the collision, spectra of electrons and identified hadrons as well as pair correlations. This talk gives an overview of the PHENIX results as presented at the *Budapest'02 Workshop on Quark and Hadron Dynamics*, Budapest, Hungary, March 3–7, 2002.

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1. Introduction

The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory started regular operations in June 2000 by colliding Au nuclei at $\sqrt{s_{NN}} = 130\text{GeV}$ energy, opening new frontiers in the study of hadronic matter under unprecedented conditions of temperature and energy density. All four experiments (BRAHMS, PHENIX, PHOBOS, STAR) performed very well in this first data taking run, collecting data from several millions of collisions. The first preliminary results were shown at the Quark Matter '01 conference and many of the final results are published since. There were many interesting and unexpected observations spurring a large amount of theoretical activity during the past year, but the answer to the tantalizing question - has the Quark-Gluon Plasma (QGP) been formed at RHIC yet? - has not been settled so far. On an imaginary "QGP scorecard" the results range from the spectacular to the incomprehensible - hopefully to be settled by more data to ba taken and analyzed in the next few years. In this paper we present selected results from Year-1 and an give an outlook what to expect from the Year-2 data, taken in 2001.

2. The PHENIX Experiment in Year-1

The PHENIX experiment is one of the major experiments at RHIC. Its two central spectrometer arms cover the pseudorapity range $|\eta| < 0.35$ and in $2 \times 90^{\rm deg}$ in azimuth, and offer excellent hadron, electron and photon identification. (The two muon arms were not yet instrumented during Year-1 data taking.) PHENIX is designed as a high luminosity experiment being able to search for rare processes; however, in Year-1 only about 2 million good events were collected and analyzed. The experiment is described in [1, 2].

3. Suppression of Hadrons with Large Transverse Momenta

In high-energy nuclear collisions hard scattering will occur at the earliest time during the collision, well before the QGP is expected to form, and thus the scattered partons will subsequently experience the strongly interacting medium created in the collision. These partons are expected to lose energy [3] in hot and dense nuclear matter through gluon bremsstrahlung, effectively quenching jet production. This would have many observable consequences, of which the most directly measurable would be a depletion in the yield of high p_T hadrons, making "jet quenching" a potential signature for QGP formation.

Obviously in order to quantify such depletion one has to establish a baseline expectation from nuclear collisions in the absence of nuclear medium effects. This has been done by modeling the Au+Au collision as a sum of independent nucleon-nucleon collisions and introducing the *nuclear modification factor* as the ratio

$$R_{AA}(p_T) = \frac{(1/N_{evt})\ d^2N^{A+A}/dp_T d\eta}{(\langle N_{binary}\rangle/\sigma_{inel}^{N+N})\ d^2\sigma^{N+N}/dp_T d\eta}. \tag{1}$$

where N_{binary} is the number of nucleon-nucleon collisions in a particular event class (centrality) and is calculated using the Glauber model. In the absence of nuclear modifications to hard scattering, the ratio R_{AA} is expected to be unity, departures from $R_{AA} = 1$ indicate nuclear medium effects. It should be noted that at lower c.m. energies and for $p_T > 2$GeV/c R_{AA} actually rises above 1 ("Cronin-effect" [4])

For 130 GeV Au+Au collisions PHENIX measured the nuclear modification factor for the 10% most central events [5]. Since there are no N+N data at $\sqrt{s} = 130$GeV, the $(h^+ + h^-)/2$ charge particle production cross-section has been parametrized interpolating between pp results from ISR and $\overline{p}p$ collisions at the SPS and Tevatron. Using this parametrization we obtain the nuclear modification factor R_{AA} in central Au+Au collisions as shown on Figure 1, along with the range of R_{AA} values measured in heavy ion collisions at CERN. There is a striking depletion in R_{AA} not only with respect to earlier CERN measurements, but also if compared to simple binary scaling with the number of collisions in central events. This depletion is in qualitative agreement with the predictions of energy loss by scattered partons traversing a dense medium [6].

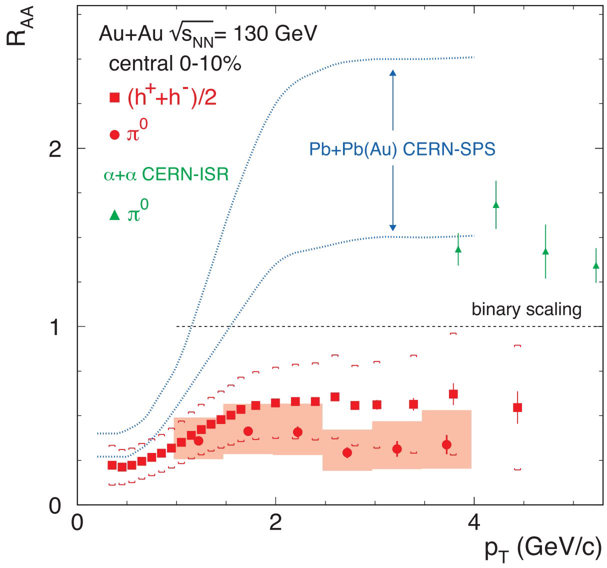

Fig. 1. The ratio R_{AA} for charged hadrons and neutral pions (combined PbSc and PbGl results) in central Au+Au collisions. The error bars indicate the statistical errors on the measurement. The surrounding bands (shaded for π^0's, brackets for $(h^+ + h^-)/2$) are the quadrature sums of (i) the systematic errors on the measurement, (ii) the uncertainty in the p+p data, and (iii) the uncertainty in $\langle N_{binary} \rangle$. Also shown for reference are the ratio of inclusive cross sections in α+α compared to p+p at $\sqrt{s_{NN}}$ = 31 GeV (CERN-ISR) and semi-inclusive spectra from central Pb+Pb, Pb+Au compared to p+p collisions at $\sqrt{s_{NN}}$ = 17 GeV (CERN-SPS) (shown as a band indicating the range of uncertainty covered by the errors on the CERN data).

4. Measurements of Single Electrons

In addition to the pion, kaon and proton spectra PHENIX was also able to measure the transverse momentum spectra of electrons [7] using the tracking system, the ring imaging Cherenkov detector and the electromagnetic calorimeter of the central arm. The majority of the observed electrons come from (1) Dalitz decays of π^0, η, η', ω, and ϕ, (2) di-electron decays of ρ, ω, and ϕ, (3) photon conversions, (4) kaon decays ($K^{0,\pm} \rightarrow \pi e \nu$). However, expected electron sources also include semi-leptonic decay of charm, and other contributions such as bottom decays and thermal di-leptons. In order to estimate the total contribution from sources (1)-(4) we used the hadron spectra measured in PHENIX for pions, kaons and protons, and a parametrization based upon SPS, FNAL and ISR results for the other particles as well as the detector simulations for photon conversions. The yield of electrons from sources (1)-(4) was calculated from a hadronic “cocktail” generator, and the results were compared to the observed total electron yield.

The result for minimum bias collisions is shown on Figure 2. The top panel shows the ratio of all observed electrons over the number of electrons expected from sources (1)-(4) (“background”); the shaded area indicates the p_T-dependent systematic error. A significant electron excess above the background is observed for $p_T > 0.6$ GeV/c, where probably the dominant source is open charm decays [7].

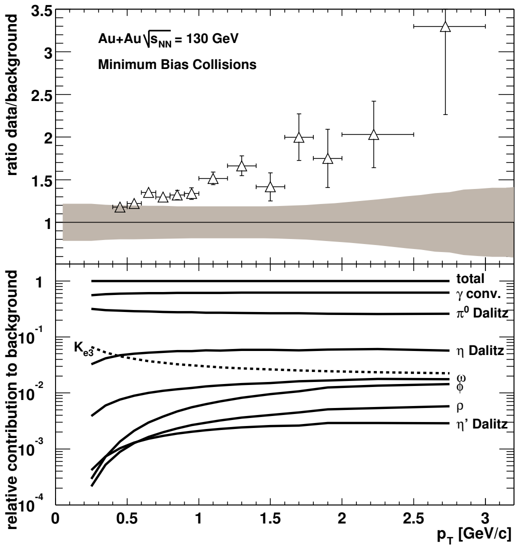

Fig. 2. Ratio of the electron data to the calculated background as a function of p_T in minimum bias collisions (upper panel) and relative contributions to the background from various sources (lower panel). The curves for ω and ϕ show the sum of the Dalitz and the di-electron decay modes.

5. Event-by-event Fluctuations

Phase instabilities near the QCD phase transition can result in non-statistical fluctuations that are detectable in final state observables [8]. These instabilities, which may occur due to random color fluctuations critical behavior at the QCD tri-critical point, or fluctuations from the decay of a Polyakov loop condensate, can result in a broadening of the transverse momentum or transverse energy distributions of produced particles for different classes of events. This phenomenon is expected to be detected experimentally by searching for deviations of the distributions of the event-by-event mean transverse momentum M_{p_T} or mean transverse energy M_{e_T}

of produced particles from the random distributions expected for statistically independent particle emission.

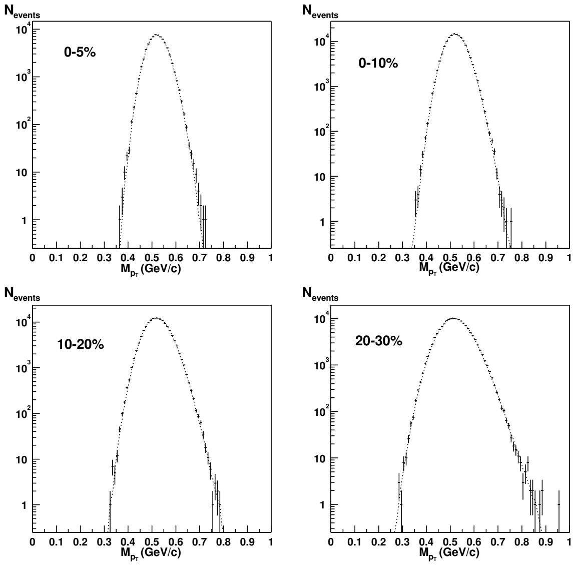

Fig. 3. The M_{p_T} distributions for all centrality classes. The curves are the random baseline mixed event distributions.

Figure 3 shows the result of the analysis of the M_{p_T} fluctuations in different event centrality classes. The histograms are the observed fluctuations while the curves correspond to completely random fluctuations derived from mixed events. The data and mixed event distributions are virtually indistinguishable. However, it should be pointed out that the Year-1 acceptance was quite limited.

The sensitivity of this precision measurement to non-statistical fluctuations has been evaluated using the dual event class model and the prescription in [9]. The resulting sensitivity-curve is shown on Figure 4. We expect to improve significantly upon the sensitivity with the increased Year-2 acceptance.

6. Conclusions and Outlook

The PHENIX experiment published 13 papers from Year-1 data (Au+Au collisions at 130 GeV), and the scope of the analyses ranges from global observables, like charge multiplicity and transverse energy distribution to inclusive hadron and electron spectra as well as correlation analyses. By the time of this Conference the second (Year-2) run was also completed. PHENIX collected $26\mu b^{-1}$ data of Au+Au collisions at $\sqrt{s_{NN}} = 200$GeV and a comparable amount of polarized pp data at the same energy which will allow us to establish our own NN baseline, within the same

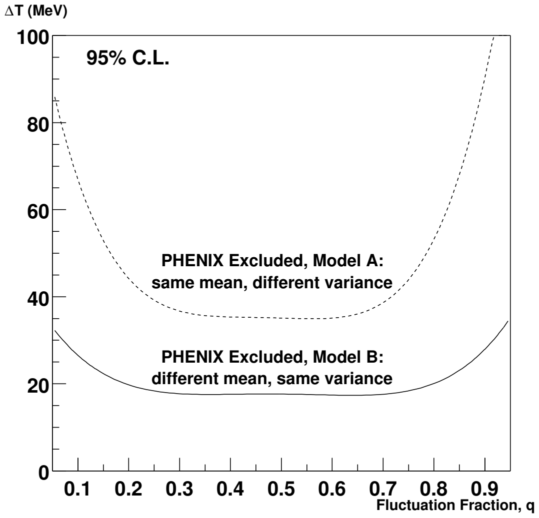

Fig. 4. The PHENIX sensitivity to non-random fluctuations in the two variations of the dual event class model that are excluded at the 95% confidence level by the M_{p_T} analysis in the $0-5\%$ centrality class. The fraction of events, q, in the class of events with the lower inverse slope parameter (event class 1) is plotted on the horizontal axis while the difference in inverse slope parameter between event class 1 and event class 2, ΔT, is plotted on the vertical axis. The curves represent the lower boundaries of the excluded regions.

experiment and with the same systematics. Equally important, in Year-2 the central spectrometer has been fully instrumented; the increased acceptance and integrated luminosity will allow to establish hadron spectra beyond 10 GeV/c. Finally, the South Muon Arm of PHENIX was also instrumented.

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