Inclusive Particle Spectra and Exotic Particle Searches Using STAR

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The STAR experiment at RHIC will search for evidence of the Quark-Gluon Plasma using a large variety of inclusive and event-by-event measurements. Nucleus-nucleus collisions at RHIC will produce thousands of charged particles per event, and STAR will measure a large fraction of these. The STAR detector capabilities will be discussed, as well as selected physics topics that will be pursued early in the STAR program.

1 Introduction

The Relativistic Heavy-Ion Collider (RHIC) at BNL will be a unique experimental environment. The accelerator is capable of colliding nuclear species ranging from polarized protons to gold at center-of-mass energies of roughly 60 GeV [a] to 200 GeV (Au+Au) to 500 GeV (p+p). The high-energy nucleus-nucleus collisions will produce the largest final-state multiplicities ever seen in a laboratory, with predicted $dN_{ch}/d\eta > 1000$ for central Au+Au collisions.

The STAR detector is a large acceptance multi-purpose detector that will measure a large variety of observables, and correlations among these observables on an event-by-event basis. A primary goal of high-energy nucleus-nucleus collisions is to search for and study the deconfined state of strongly interacting matter known as the Quark-Gluon Plasma (QGP). STAR will search for such a state by measuring (among other things) inclusive particle spectra and yields, two-particle correlations, strange particle production, and collective phenomena such as flow. STAR will also look for fluctuations and correlations among these observables on an event-by-event basis.

2 The STAR Detector

The Solenoidal Tracker At RHIC (STAR)[1,2] (Figure 1) is designed to measure and identify charged particles in the mid-rapidity region ($\eta < 1$) with nearly

[a] Injection into the RHIC ring occurs at $\sqrt{s} \approx 20$ GeV, so the lower limit is primarily driven by luminosity considerations.

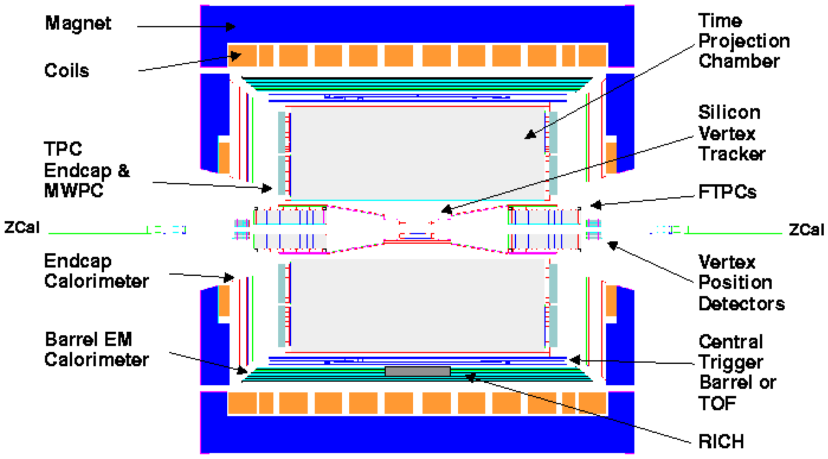
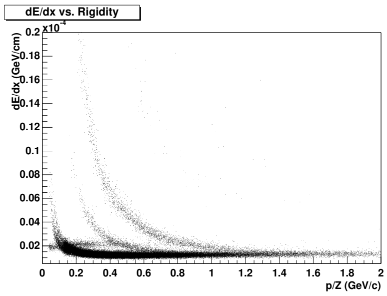


Figure 1: The STAR detector.

complete azimuthal coverage. The detector is enclosed in a 0.5 Tesla solenoidal magnet that allows for charged-particle momentum determination. Additional detectors will extend the charged-particle measurements out to $\eta = 4$, and the installation of Electromagentic Calorimeters will allow for γ and π^0, and e measurements.

The central tracking detector is a large Time-Projection Chamber (TPC) that covers the pseudo-rapidity range $\eta < 1.8$. The primary ionization drifts to the TPC ends and is amplified and collected with 24 multi-wire proportional chambers using cathode pad plane read-out. Each multi-wire proportional chamber has 45 pad rows which give up to 45 independent three-dimensional position and energy loss measurements for each track. The energy loss measurements are used to identify particles via dE/dx. Figure 2 shows a simulation of the dE/dx vs. rigidity measurements expected from the STAR TPC. The expected dE/dx resolution of the TPC is 7%, allowing for $K - \pi$ separation up to 600 MeV/c and $p - \pi$ separation up to 1.1 GeV/c.

In order to substantially improve the high-p_T momentum resolution and strange particle reconstruction efficiency, a silicon vertex tracker (SVT) and silicon strip detector (SSD) will be installed in year 2 of STAR operation. The SVT consists of 3 layers of silicon drift detector. One layer of silicon strip detector will surround the SVT. The silicon drift detectors should achieve



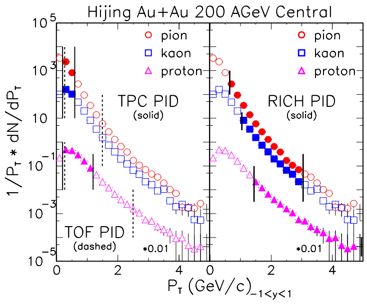


Figure 2: A simulation of the expected dE/dx vs. rigidity measurement from the STAR TPC (left panel) and the PID ranges from the RICH (right panel).

position resolution of $15\mu m$ which will allow for very accurate momentum determination on tracks with a small sagitta.

Charged particles will be measured in pseudo-rapidity range $2 < |\eta| < 4$ using two Forward Time Projection Chambers (FTPC) that will be installed for year 2 of STAR operation. These detectors use a radial drift field in order to magnify the large η region near the beam-pipe where track density is highest.

γ, e, and π^0 will be measured using Electromagenetic calorimeters (EMC) that will be gradually installed during the first 3 years of STAR operation. A barrel calorimeter covers $|\eta| < 1$ and one End Cap calorimeter covers $1 < \eta < 2$. The detectors are Pb+Scintillator sampling calorimeters with shower maximum detectors for γ/π^0 separation.

A Ring Imaging Cerenkov will give intermediate momentum particle identification (PID) is a small phase-space region (1/60th of TPC acceptance). This detector allow pion, kaon and proton identification up to momenta 3, 3, and 5 GeV/c, respectively. Figure 2 shows a comparison of the STAR PID performance with the TPC only and with the additional RICH. In addition, a small time-of-flight patch is under development to give additional PID in a small phase-space region.

A scintillator barrel (CTB) that surrounds the TPC and measures the charged particle multiplicity will serve as a level 0 trigger. In addition, two zero-degree calorimeters that are common to all RHIC experiments allow for a trigger on event centrality. An EMC trigger will be used to select events with high-p_T photons. Fast processors will be used for online tracking in the TPC and event reconstruction to allow further selection on events of interest.

3 Soft Hadronic Physics

An early goal of STAR will be to determine the conditions produced in heavy-ion collisions at RHIC. It is almost certain that the collisions will be sufficient to create the conditions thought to be necessary for Quark-Gluon Plasma formation. A lower limit on the mid-rapidity energy density at first equilibration can be determined by measuring the charge particle multiplicity and using the Bjorken estimate [3],

$$\epsilon_0 = \frac{3}{2}\frac{m_T}{\tau_0 R}\frac{dN_{ch}}{d\eta}, \tag{1}$$

where m_T is the mean transverse mass of the produced particles, τ_0 is the proper time at which a plasma is produced (of order 1 fm/c), and R is the initial transverse size of the system. Energy densities of several GeV/fm^3 are expected at RHIC.

In addition to the total energy density, it is important to know the net baryon density in RHIC collisions. The net baryon density can be related to the baryon chemical potential. It is expected that the baryon chemical potential will be small in the mid-rapidity region at RHIC which will cause the QGP phase transition to be completely temperature driven. Such a baryon free system can be accurately modeled by lattice QCD. STAR should give an excellent handle on the mid-rapidity baryon density, as STAR will be able to measure a large majority of the (anti-)baryons near mid-rapidity, including p, Λ, Ξ and Ω.

In recent years, the analysis of heavy-ion data has led to the realization that two temperatures are manifest in the final state [4]. The "chemical" temperature is important for determining the particle abundances, while the "kinetic" temperature characterizes the momentum distribution of the produced particles. At AGS and SPS energies, chemical freeze-out seems to occur at a higher temperature than kinetic freeze-out. STAR, through a simultaneous measurement of the yields and spectra of many hadron species, will look for evidence of chemical and kinetic equilibration at RHIC. In addition, STAR can also measure two-particle correlations that can be coupled with the single inclusive measurements to further constrain the chemical and kinetic freeze-out scenarios.

4 Anti-nucleosynthesis

Mid-rapidity Light (anti-) nuclei are formed in high-energy heavy-ion collisions via final-state coalescence. They give information about the final-state configuration in both momentum and position space, and therefore provide a useful

Table 1: Coalescence Parameters[6] and Production Rate estimates for light anti-nuclei

	B_A	$\frac{dN}{dy}\|_{y=0}$
$\overline{p}$	-	8
$\overline{d}$	1.5×10^{-3}	1×10^{-1}
$\overline{t}, ^3\overline{He}$	5×10^{-6}	2.5×10^{-3}
$^4\overline{He}$	2×10^{-9}	8×10^{-6}

consistency check on the information extracted via HBT. The rate of (anti-) nucleus production has been shown to follow a simple scaling[5],

$$E_A \frac{d^3 N_A}{dp^3} = B_A (E_p \frac{d^3 N_p}{dp^3})^A, \tag{2}$$

where A is the mass number of the produced nucleus, and B_A is the coalescence parameter.

RHIC presents a new opportunity to study the production of light anti-nuclei. The C.M. energy at RHIC is well above the anti-nucleon threshold, so RHIC will have the highest anti-nucleon production rates ever seen in a laboratory. Table 4 shows a simple prediction for the light anti-nucleus production rates at RHIC. The coalescence parameters are taken from previous measurements[6]. We assume that the coalescence parameters are similar for nuclei and anti-nuclei. Additionally, we assume that the coalescence parameters do not change dramatically between AGS and RHIC energies. The $\overline{p}$ yield is extracted from RQMD calculations, and the $\overline{A}$ yields are calculated using Equation 2. STAR can identify these particles via dE/dx in the TPC. In a year of running, STAR should be able to measure 10^7 Au+Au events, which corresponds to roughly 100 $^4\overline{He}$ per year. With additional triggering on $Z = -2$ tracks in the TPC, this rate can be increased substantially.

5 High-p_T physics

The large C.M. energy at RHIC will allow high-p_T ($p_T > 5$GeV/c) particles to be measurable for the first time in nuclear collisions. In principle, the rates for such processes are calculable from perturbative QCD. Hence, any deviation from the calculated rates is direct evidence of new physics in high-energy nuclear collisions.

It is thought that a parton traveling through a dense medium will lose energy, and that this energy loss (dE/dx) is sensitive to the partonic density[7,8]. There have been several suggestions about how to identify and quantify parton energy loss. A simple measurement of the high-p_T particle spectrum and a comparison to QCD predictions leaves some ambiguity about the source of any deviation from QCD. High-p_T partons fragment into jets, but the high multiplicities expected at RHIC make full jet reconstruction impossible. One can measure the leading hadron in a jet, but the relation between the leading hadron and the parent parton depends on the fragmentation function, which may be modified in nucleus-nucleus collisions.

With the addition of the EMC barrel, STAR will look for high-p_T hadrons opposite a high-p_T photon. Since a parton is always produced opposite a high-p_T photon, the photon can be used to measure the initial energy of the parton [8].

6 Exotic Particle Searches

Because of its limited luminosity, RHIC will not be competitive with other accelerators for exotic particles searches unless the Quark-Gluon Plasma is a necessary pre-condition for production. One candidate particle is the strangelet [9]. Extensive searches have been performed at lower energies [10], but in these cases there is no evidence for the production of a long-lived Quark-Gluon Plasma in such collisions. Some calculations suggest that strangelets will be produced from a Quark-Gluon plasma. STAR can identify these strangelets by looking for particles with an anomalous charge to mass ratio ($Z/A < 0.3$). In addition, STAR can reconstruct the multi-particle decay channels indicative of certain strangelets.

Another class of exotic particles that may be visible only in high-energy nucleus-nucleus collisions are fractionally-charged particles. Although it is believed that confinement is absolute in QCD, an extended Quark-Gluon Plasma creates a unique situation where $q\overline{q}$ pairs may become separated over relatively large distances (> 20fm/c). Given a small gluon mass, free fractionally-charged particles become possible. STAR will look for such particles using TPC $dE/dX \propto Z^2$ as was done previously with the PEP-4 TPC [11].

7 Status of STAR

At the time of this conference, the STAR baseline detector is essentially complete and ready for first RHIC collisions. The magnet, TPC and central trigger barrel are installed in the interaction region and fully instrumented. Cosmic and laser test data has been taken with and without the magnetic field. As RHIC was being commissioned, a few "beam+something" events were observed.

8 Conclusions

STAR is a large acceptance multi-purpose detector at RHIC. STAR will measure a large number of observables, and be able to correlate among these observables on an event-by-event basis. Inclusive hadron spectra will be used to establish the initial conditions and probe the freeze-out conditions. Anti-nuclei will be used to understand the final-state anti-nucleon distribution. High p_T measurements will be compared with pQCD predictions to look for evidence of parton energy loss. STAR will also search for strangelets and fractionally-charged particles.

Acknowledgments

This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Division of Nuclear Physics of the U.S. Department of Energy under Contracts DE-AC03-76SF00098 and DE-FG02-92ER40713.

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