

The STAR Experiment at RHIC

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1. Introduction

STAR (Solenoidal Tracker at RHIC) will be one of two large, sophisticated experiments ready to take data when the Relativistic Heavy Ion Collider (RHIC) comes on-line in 1999. The design of STAR, its construction and commissioning and the physics program using the detector are the responsibility of a collaboration of over 250 members from 30 institutions, world-wide.

The overall approach of the STAR Collaboration to the physics challenge of studying collisions of highly relativistic nuclei is to focus on measurements of the properties of the many hadrons produced in the collisions. The STAR detector is optimized to detect and identify hadrons over a large solid angle so that individual events can be characterized, in detail, based on their hadronic content. The broad capabilities of the STAR detector will permit an examination of a wide variety of proposed signatures for the Quark Gluon Plasma (QGP), using the sample of events which, on an event-by-event basis, appear to come from collisions resulting in a large energy density over a nuclear volume.

In order to achieve this goal, the STAR experiment is based on a solenoid geometry with tracking detectors using the time projection chamber¹ approach and covering a large

range of pseudo-rapidity so that individual tracks can be seen within the very high track density expected in central collisions at RHIC. STAR also uses particle identification by the dE/dx technique and by time-of-flight. Electromagnetic energy is detected in a large, solid-angle calorimeter. The construction of STAR, which will be located in the Wide Angle Hall at the 6 o'clock position at RHIC, formally began in early 1993.

2. Physics Program of STAR

The physics goals of the STAR Collaboration which includes searching for the Quark Gluon Plasma, studying the dynamics of relativistic nuclear collisions and studying the parton physics of extended hadronic matter is described in detail elsewhere^{2,3,4,5}. The analysis approach for this experiment will be the correlation of many observables on an event-by-event basis. In order to understand the underlying physics, and to identify the QGP, the STAR physics program will require measurements using proton-proton, proton-nucleus, and nucleus-nucleus collisions under a wide variety of conditions so that the dependence on impact parameter, incident energy and nuclear species can be understood. The large acceptance, good momentum and two-track resolution and particle identification characteristics of the STAR experiment will permit event-by-event measurements of many observables related to QGP signatures and collision dynamics such as particle spectra, flavor composition, source size, and density fluctuations in energy, entropy and multiplicity in azimuth and pseudo-rapidity (η). In addition, measurements of the remnants of hard-scattered partons will provide important new information on the nucleon structure functions and parton shadowing in nuclei in a regime where there is a high enough energy for perturbative QCD to give a useful description of the hard parton scattering⁶.

3. The STAR Detector

The configuration of the STAR detector is illustrated in figure 1. The RHIC colliding beams collide in the center of the detector. Moving radially outwards from the beampipe, particles first encounter a vertex chamber based on silicon drift technology. This device,

which is called the Silicon Vertex Tracker (SVT), consists of three layers of ladders of silicon drift devices to provide three independent space points with a resolution of less than 50 microns and three samples of ionization for each track that traverses the device. In essence, the SVT is a silicon time projection chamber with over 100,000 channels of TPC-like electronics. The full SVT covers $|\eta| \leq 1$ with one layer covering $|\eta| \leq 2$.

Beginning at 50 cm radially from the beam collision point is the large, central TPC. The central TPC, which has a diameter of 4 m and a length of 4.2 m, will provide intrinsically three-dimensional space points and ionization samples for 45 radial points along tracks between $|\eta| \leq 1$ using 45 rows of cathode pads on the endcap sectors and fewer points and ionization samples for $1 \leq |\eta| \leq 2$. Each cathode pad is sampled 512 times during the 40 microsecond TPC drift time resulting in 71 million r - θ - ϕ pixels within the TPC. It is this high degree of segmentation that gives the TPC its unique power to detect individual tracks within the very high track multiplicity expected at RHIC.

The spatial resolution of the central TPC will be about 600 microns with a resolution in dE/dx of about 7%. Tracking efficiencies of approximately 90% should be achievable in the track densities that will be typical of RHIC events and particles identification should be effective for momenta up to about 600 MeV/c. The TPC is read out with over 140,000 channels of electronics (one channel per cathode pad) based in custom integrated circuits. Each channel consists of a low-noise, charge-sensitive preamplifier, a shaper amplifier, a 512 deep switched capacitor array for time sampling in the drift coordinate, and a digitizer. The TPC is immersed in very uniform 0.5 Tesla axial magnetic field provided by the conventional solenoid magnet.

Immediately outside of the central TPC will be an array of trigger scintillation counters and time-of-flight counters. The TOF system will include 10,000 counters with 100 picosecond time resolution covering the barrel for $|\eta| \leq 1$.

★ STAR DETECTOR

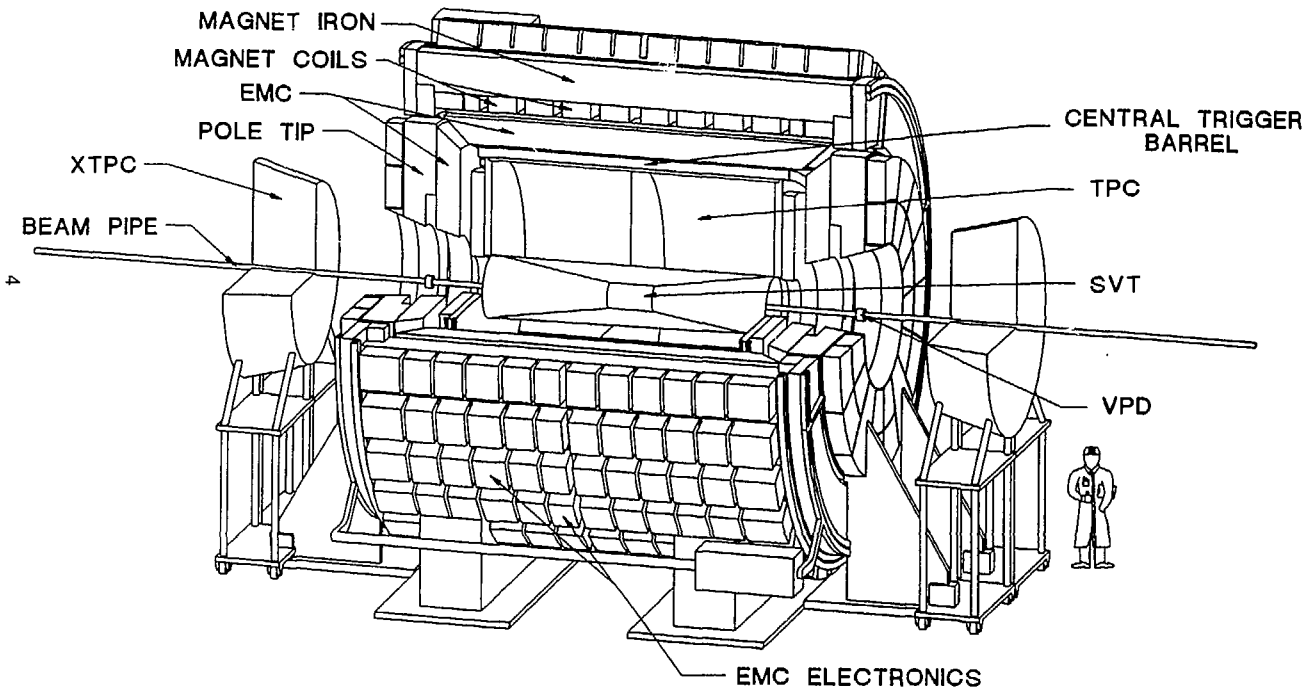


Figure 1 Overview of the STAR Detector

The TOF system will identify hadrons with p_T greater than 0.3 MeV/c with pions and kaons identified up to $p_T=1.5\text{GeV}/c$, and protons and antiprotons to $p_T=2.3\text{ GeV}/c$.

Outside of the TOF system, covering $|\eta| \leq 1$ is the barrel electromagnetic calorimeter (EMC). The barrel EMC is a multilayer lead/scintillator sampling calorimeter with 1200 towers arranged in η and ϕ . Signals from the barrel EMC are taken through the gaps between the magnet coil pancakes and through the iron yoke segments to phototubes on the outside of the detector.

The STAR detector also includes endcap electromagnetic calorimeters that cover the magnet poletips between $1 \leq |\eta| \leq 2$ and external time projection chambers (XTPC) to provide tracking information and charge identification between $2 \leq |\eta| \leq 4.5$. The XTPCs will use radial drift to allow separation of individual tracks, even in the very dense region at the highest pseudo-rapidity covered.

The STAR trigger is designed to operate at a number of levels, allowing more and more sophisticated decisions to be made as the information from various detectors becomes available for processing. The trigger approach includes the preservation of information from all trigger detectors in the data stream so that increasingly sophisticated and relevant algorithms can be developed as the appropriate physics observables are better understood. The basic trigger for STAR consists of a multiplicity trigger formed from 240 trigger elements around the TPC barrel and from fast signals from the anode wires on the TPC endcap. The overall detected multiplicity and the multiplicity distribution in the η and ϕ pixels defined by these elements forms the primary level 0 trigger. There is also a veto calorimeter at zero degrees and a vertex position detector that is used in the level 0 trigger to limit the interaction point within the interaction diamond. Fast signals from the calorimeter and TOF, and then slow signals from the TPC and SVT will be available for more sophisticated algorithms that operate at the higher trigger levels.

The STAR data acquisition system must have sufficient bandwidth to accommodate the tens of megabytes of data from each event at an input rate of up to 100 hertz, to operate on this data with sophisticated level 3 trigger algorithms in order to choose the most interesting events and then to write data into a storage medium at 1 hertz. A number

of high-bandwidth communications networks are being evaluated as the backbone of the STAR data acquisition system.

Figure 2 illustrates the overall pseudo-rapidity coverage of the STAR tracking systems for a single FRITIOF Au-Au collision at a center of mass energy of 200 GeV per nucleon. The central TPC for tracks between $|\eta| \leq 2$ and the XTTPC for $2 \leq |\eta| \leq 4.5$ covers a large fraction of the charged tracks in the event. Figure 3 illustrates the particle identification coverage as a function of the transverse momentum of both pions and kaons emitted in a single Au-Au collision. Most of the particles that are not identified either interact or decay in flight.

An overview of the STAR detector systems is given in Table 1.

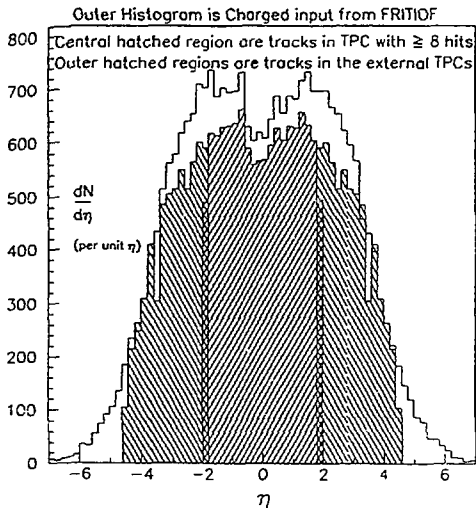


Fig. 2 The outer histogram displays the $dN/d\eta$ distribution that is input from the FRITIOF event generator. The hatched histograms represent the $dN/d\eta$ distributions reconstructed from tracking in the central and external TPCs.

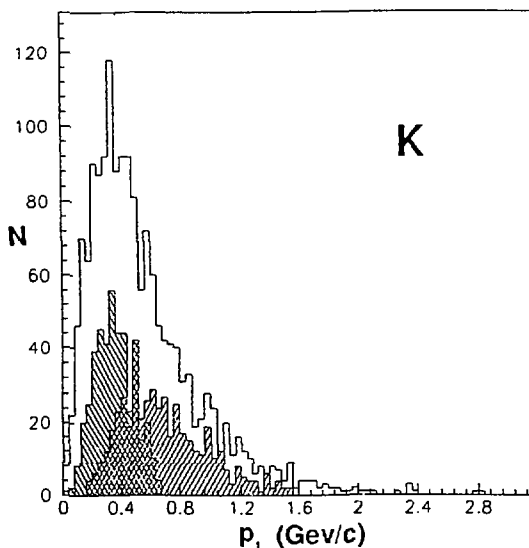
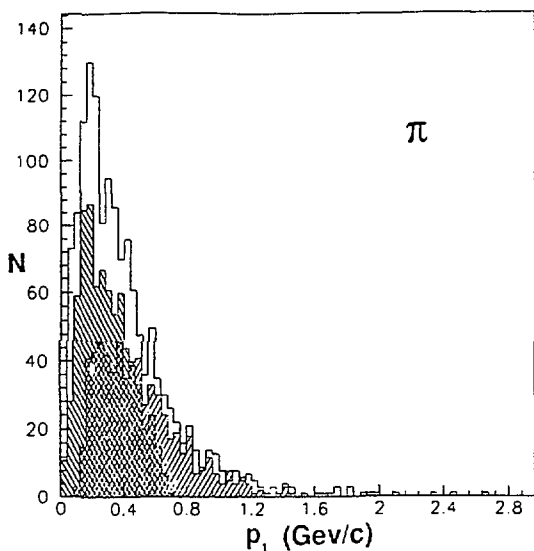


Fig. 3 Transverse momentum distribution, dn/dp_t , for charged pions (above) and kaons (below) from the primary interaction vertex generated by the Lund/FRITIOF nucleus-nucleus code and tracked through the experimental setup. The $\backslash\backslash\backslash$ region contains those particles identifiable with dE/dx measurements in the TPC. The $///$ region contains particles identified by TOF. The cross-hatched region has particles identified by both methods and the open region by neither. Most of the particles which are not identifiable and appear in the open region either interact or decay in flight.

Table 1 Overview of STAR detector systems

Solenoidal Magnet	
Coil Inner Radius	2.62 m
Length	6.9 m
Field Strength	0.25 - 0.5 T
Time Projection Chamber (TPC)	
Inner Radius	0.5 m
Outer Radius	2.0 m
Length	4.2 m
# of Channels	136,240
Acceptance	$ \eta \leq 2.0$
Trigger Detectors	
Vertex Position Detectors	
Segmentation	20 elements
Acceptance	$3.3 < \eta < 3.8$
TPC Endcaps (MWPC)	
Segmentation	2,000
Acceptance	$1.0 \leq \eta \leq 2.0$
Veto Calorimeters	
Segmentation	to be determined
Acceptance	$ \eta > 5$
Central Trigger Barrel (Scintillator)	
Segmentation	200
Acceptance	$ \eta \leq 1$
Silicon Vertex Tracker (SVT) R&D Project	
Type	Si Drift Chambers
Radius 1st layer	5 cm
Radius 2nd layer	8 cm
Radius 3rd layer	11 cm
Length	42 cm
# of Channels	83,000
Acceptance - 1st, 2nd, 3rd layers	$ \eta \leq 2.1, 1.7, 1.4$

EM Calorimeter Upgrade	
Inner Radius	2.20 m
Thickness	0.325 m
Segmentation	$\Delta\eta, \Delta\phi = 0.105, 0.105$
# of Channels	1200
Acceptance	$ \eta \leq 1.05$
Time-of-Flight Upgrade	
Type	shingle slats
Inner Radius	2.06 m
# of Channels	7776
Acceptance	$ \eta \leq 1.0$
External TPC Upgrade	
Number of Modules at Each End	4
Dimensions of Each Module(LxWxD)	2.2 x 2.0 x 1.0 m ³
Z Distance to Front Face	7.0 m
Total # of Channels	22,000
Acceptance	$2.0 \leq \eta \leq 4.5$

4. Status of STAR

STAR was approved for construction in early 1993 by the Brookhaven National Laboratory management based on advice from their Program Advisory Committee and from the RHIC Technical Advisory Committee. This approval followed many rounds of review of the STAR Collaboration's letters of intent, physics proposal and the conceptual design report and associated cost, schedule and management plans for STAR. The USDOE concurred with this approval in March 1993.

STAR will be funded and constructed in several phases. The so-called baseline is funded primarily from RHIC construction funds and from resources provided by the Collaboration. This baseline includes the solenoid magnet and associated support structures, the central TPC and its electronics, the data acquisition and trigger systems, and the computing and software development needed to begin the physics program. In

addition, the engineering necessary to integrate the other detectors (SVT, EMC, TOF, XTPC) into the baseline in the future is being done to assure that all envisioned detector systems of STAR can be installed and operated without undo disruption of the physics program.

During the early years of STAR construction, R&D is proceeding on the SVT, TOF, EMC and XTPC so that the technologies of choice can be proven and a viable conceptual design for these systems can be developed. It is the goal of the STAR Collaboration to seek funding from U.S. and other sources so that these systems will be constructed and operating as close to the time of initial RHIC operations as possible.

At the present time, construction of the STAR baseline is moving ahead rapidly. Construction of the endcap sectors for the TPC should begin in a few months based on a successful prototype that is now undergoing detailed tests. A 90kV prototype high voltage insulator for the TPC is under test. The design and prototyping of the electronics for the TPC is almost complete and the first 15% of the TPC electronics will be procured from industry within the next nine months. The magnet design is essentially complete and the process of procuring the coil is taking place. In addition, the design of the additional assembly building, utilities and other infrastructure needed at the RHIC site for STAR is complete with construction on these items scheduled to begin in a few months.

We expect cosmic ray testing of the TPC to begin in early 1996, the magnet construction to be completed in mid-1997 followed by installation of the TPC, trigger detectors, electronics and data acquisition systems leading to cosmic rays tests of the baseline STAR detector in the second half of 1998. STAR will be ready to begin its physics program in March 1999 when beams first collide at RHIC and we expect that significant parts of the remaining systems (SVT, EMC, TOF and XTPC) will be on-line soon thereafter.

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