STUDIES OF HOT AND DENSE NUCLEAR MATTER

PROGRESS REPORT

January - December 2001

S. P. Sorensen & K. F. Read

January 25, 2002
Progress Report on

STUDIES OF HOT AND DENSE NUCLEAR MATTER\textsuperscript{1}

2001

SOREN P. SORENSEN AND KENNETH F. READ

Department of Physics and Astronomy
University of Tennessee
Knoxville, TN 37996-1200

January 25, 2002

\textsuperscript{1}Research supported by DOE contract DOE DE-FG02-96ER40982, January 1, 2001 - December 31, 2001.
Contents

1 Introduction

2 PHENIX Related Research
   2.1 The PHENIX Muon Arms ........................................... 3
   2.2 Commissioning of the MuID Front End Electronics ............... 3
      2.2.1 Noise Studies ........................................... 3
      2.2.2 Detector Timing ......................................... 4
   2.3 High Voltage .................................................. 5
   2.4 Two-pack Efficiencies ......................................... 5
   2.5 Online Monitoring ............................................ 6
   2.6 Muon Mock Data Challenge ...................................... 7
   2.7 MuID Offline Computing ....................................... 8
   2.8 Muon Level 2 Trigger .......................................... 9
   2.9 Shielding Study ............................................... 12

3 Publications and Talks ................................. 15
   3.1 Refereed Publications ....................................... 15
   3.2 Talks or Invited Participation ............................... 15

4 Financial Issues .......................................... 17
STUDIES OF HOT AND DENSE NUCLEAR MATTER
The University of Tennessee

GROUP MEMBERS

FACULTY: Prof. Soren P. Sorensen (PI), Assoc. Prof. Kenneth F. Read.

RESEARCH ASSOCIATES: Dr. George Gogiberidze, Dr. Laurence Villatte.

GRADUATE STUDENTS: Andrew Glenn, Jason Newby, Stephanie Steffens.

ACCOMPLISHMENTS AND HIGHLIGHTS IN 2001

- Leading and coordinating the construction, commissioning, and operation of the PHENIX Muon Identifier (MuID) as Detector Council representative for this subsystem (Ken). Pushing MuID-readiness so that MuID was part of the global PHENIX data collection by the end of the first year's running in 2000 and participated fully in the Au+Au and p+p runs in 2001-2002. Coordinating preparations for operation of the north MuID in 2002.
- Frequent chairing of the Muon Software teleconferences, Muon Budget teleconferences, Muon Commissioning meetings, and MuID teleconferences. Co-organization of PHENIX Muon Arms Group meetings.
- Commissioning of the MuID Front End Electronics, including studies of the noise levels and detector timing.
- Commissioning of the MuID High Voltage System and partial development of control software.
- Performed evaluations of the MuID Detector efficiencies.
- Development of the MuID online monitoring tools.
- Played a leading role in the Muon Mock Data Challenge as MDC manager.
- Continued the development of the key module, the roadfinder, in the MuID offline software chain.
- Performed the analysis and simulations responsible for the development of the MuID Level 2 trigger.
- Performed all aspects of the studies leading to the installation of additional shielding in the MuID square-hole close to the beam pipe resulting in substantially reduced background hit rates.

FUNDING SUPPORT (1999-2002)

<table>
<thead>
<tr>
<th></th>
<th>99-00</th>
<th>00-01</th>
<th>01-02</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOE/Nuclear Physics</td>
<td>$218,000</td>
<td>$218,000</td>
<td>$218,000</td>
</tr>
</tbody>
</table>
1 Introduction

2001 was the 6th year the Relativistic Heavy Ion Physics (RHIP) group at the University of Tennessee (UT) had its own research contract. The contract started June 1, 1996. Since its beginning, the RHIP group has focussed its research on three topics within the large domain of Relativistic Heavy Ion Physics:

Nuclear Matter at Extreme Temperatures and Densities: We are investigating the properties of nuclear matter at high densities and temperatures with special emphasis on detecting the Quark-Gluon Plasma (QGP).

Modification of Vector Meson Properties in Hot and Dense Nuclear Matter: Among the many proposed signatures for the QGP, we are convinced that the proposed modifications of the properties of vector mesons in hot and dense nuclear matter provides the best tool for observing the QGP and for measuring the properties of the QGP. We are specifically studying the suppression of the $J/\psi$ and $\Upsilon$ resonances using the PHENIX muon detector.

Nuclear Stopping Power and Attained Energy Densities: The most important prerequisite for the creation of the QGP in ultra-relativistic heavy ion reactions is a large nuclear stopping power so that sufficiently high energy densities will be achieved in the central fireball. We have studied this topic through calorimetric measurements at WA98 and through slow proton emission in the target fragmentation region at E910.

Over the last 6 years we have studied these topics primarily through three experiments: PHENIX and E910 at BNL and WA98 at CERN. Both WA98 and E910 have long ceased to accumulate data and also the data analysis and paper publishing activities are tapering off, especially for WA98. PHENIX, however, started to to take data with the south muon arm in 2001. So, this year our progress report is entirely focussed on the activities in PHENIX in which we have been involved.

The group is primarily involved with and responsible for the Muon Identifier subdetector in PHENIX: Ken is Detector Council representative for the Muon Identifier system and Soren is working on software for the reconstruction and analysis of muon arm data. Two post-docs, George and Laurence, and our students, Andy and Jason, have all been stationed at BNL in 2001 and have been heavily involved in developing and commissioning the infrastructure of the PHENIX Muon Identifiers, both from a hardware and software aspect.

The RHIP group consisted in 2001 of:

Soren P. Sorensen: Principal Investigator, Professor and Department Head. Member of PHENIX, E910 and WA98. The headship does take a substantial amount of time and this year Soren has been less active in PHENIX than previously.

Kenneth F. Read: Associate professor at UT and research staff member at ORNL, Detector Council representative for the PHENIX Muon Identifier. Member of PHENIX and E910.

George Gogiberidze: Post-Doctoral Research Assistant. George started as a post-doc in January 2001 and left for a position in the medical imaging group at Sloan-Kettering
by Dec 31, 2001. He was responsible for all aspects of event and detector simulation and worked also on monitoring of the MuID high voltage system.

**Laurence Villate:** Post-Doctoral Research Assistant. Laurence started as a post-doc in June 2001 and will be returning the France in early summer of 2002. She got her PhD, from Orsay based on data from the NA50 experiment. Laurence has been responsible for diagnosing background problems in the MuID and for implementing shielding solutions to these problems. Based on her experience from NA50, she will also work on algorithms for subtraction of the uncorrelated background in the dimuon invariant mass spectra.

**Jason Newby:** Fifth-year graduate student. Member of PHENIX. Has been involved with testing and implementing of front-end electronics, testing and developing offline event reconstruction for the MuID, developing Level 2 trigger algorithms, and was the overall coordinator of the Muon Mock Data Challenge. Jason is scheduled to finish his Ph.D. during the 2002-2003 academic year with $J/\psi$-suppression as his thesis topic.

**Andrew Glenn:** Fifth-year graduate student. Has been involved with on-site testing and implementing of front-end electronics, in particular the noise and timing studies, monitoring of high voltage and detector performance online, and studies of the efficiencies of the detector elements in the MuID. Andy is likely to finish his Ph.D. during the academic year 2003-2004 with a thesis topic derived from the Muon Arms, probably pT-dependence of single muon production.

**Stephanie Steffens:** Second-year graduate student. Participated in simulations of the estimated muon trigger performance for the PHENIX spin program. For personal reasons Stephanie decided to pursue a Master degree instead of a Ph.D. and therefore decided to switch to another group within the Department of Physics.

George Gogiberidze will be replaced as our primary post-doc in March-April by Vasily Djordjadze, who is currently at DESY working on the TESLA project and the HERMES experiment. Vasily has previously collaborated with us in WA98. We are looking forward to have him stationed at RHIC as our main “go to guy” there.

## 2 PHENIX Related Research

After almost a decade of preparation, PHENIX has now entered the exciting phase of being a running experiment. The south muon arm is a fully operational part of PHENIX routinely collecting data. PHENIX has already published several papers and has quite a few more in preparation. We look forward to working on papers concerning muon physics.

Since a progress report is not the place to be shy, we would like to take some credit for these accomplishments through our involvement since the beginning in PHENIX. UTK is one of the most active institutes in the Muon Identifier team. We played a pivotal role in the construction and commissioning of the south arm MuID, are now one of the lead institutes maintaining the successful operation of the MuID, and have major duties in completion and commissioning of the north MuID. With two Ph.D. students, two postdocs, and two faculty members involved, we also play a significant role in the data analysis.
Our group continues to carry out major responsibilities within the Muon Arm Detector subsystem of PHENIX. The Muon Arm work is performed in close collaboration with ORNL, which has the overall responsibility for the Muon Identifier System.

2.1 The PHENIX Muon Arms

The focus of the RHIP group continues to be the PHENIX Muon Arms. Ken is the Detector Council representative for the entire Muon Identifier (MuID) subsystem. He is responsible for coordinating all aspects of the system including mechanics, gas, trigger, commissioning, simulations, safety, budgets, and manpower.

During the past year, the MuID evolved into a fully operating subsystem routinely collecting data. The RHIP group played a major role in completing the installation of the gas system and the readout system, studying beam related backgrounds, developing a plan for an effective shield inside the square hole of the MuID, making the HV control software far more robust, developing monitoring software to assess data quality, and improving the offline analysis software. A critical contribution of the RHIP group was to develop and maintain the muon level 2 trigger software.

With two graduate students and two postdocs continuously based at BNL, UT was institute with the most (by a factor of 2) physicists continuously based at BNL working on the MuID system this past year. During the commissioning phase, the MuID group met 5 days a week for months and always had a “contact person” on call. The RHIP group played a major role in these activities for the south MuID.

Many of these activities are discussed more fully below. In summary, the south MuID was ready on-time and on-budget for Run 2, collected Au+Au and p+p data, and the north MuID is on track for operation in Run 3.

2.2 Commissioning of the MuID Front End Electronics

Instrumentation of the MuID south arm was completed in 2001. The Front End Electronics (FEE) was exercised extensively through commissioning and physics data taking. The High Energy Reactions Group (HERG) at ORNL produced the forty (plus spares) readout cards (ROCs) necessary for operation of the south arm. Our two UT graduate students played a central role in the installation of the ROCs and other components as well as in the commissioning of the FEE system.

2.2.1 Noise Studies

One important aspect of the commissioning, for which in particular Andy Glenn was involved, was the characterization and reduction of noise in the FEE system. Noise in the system was initially found to be higher than expected. Various tests involving filtering capacitors and grounding schemes were investigated. This was particularly important in order to determine the operational value for the ROC’s digital to analog converter (DAC) threshold voltage. This value basically determines how large a signal pulse must be in order to constitute a “hit.” It was found that when this value was set too low, a problem akin to feedback oscillations caused noise in the ROCs to become overwhelming. The largest
single improvement in overcoming this effect came from connecting the analog and digital reference voltages at the power supplies and on each of the ROCs.

Once the system noise was reduced as much as reasonably possible, the operational value of the DAC threshold voltage was determined. Although this value can be set on a ROC-by-ROC basis, a system-wide value is being used because the minimal gains of increased granularity do not currently justify the logistical complications. This system-wide value was obtained by analyzing forced-accept data taken at different DAC threshold voltages to determine the fraction of channels with a false hit rate above an acceptable value. From the data shown in Figure 1, a threshold voltage of 90 mV was chosen.

![Threshold Scan](image)

**Figure 1:** Threshold Scan.

### 2.2.2 Detector Timing

Our two UT graduate students also played an active role in timing—in the MuID detector. The detector signals had to be delayed so that they arrived within a narrow time window. Delays can be set at multiple stages and in various increments. The optimal internal detector delays for the FEE were determined primarily through calculations by Vince Cianciolo (ORNL), but much of the verification was the responsibility of UT. Several iterations were needed to obtain a set of satisfactory delays. The MuID then needed to be delayed so that the signals arrived at the same time as the other detectors. This was accomplished primarily through the Global Level 1 delay setting inside the MuID Granual Timing Module. Figure 2 (a) shows a scan of this value in increments of beamclock cycle for one particular signal cable. Figure 2 (b) shows a distribution of the mean of the scan for all signal cables. The detector is currently operating in “slow gas mode,” so the data is valid for two clock ticks. This means that the slight spread in the distribution of the means is not a true cause for concern.
The MuID high voltage system consists of 300 individually controllable channels. Two of the main components of the HV system are an Input Output Controller (IOC), located in the PHENIX counting house, and three LeCroy HV mainframes, located in the experimental hall. The hardware is controlled through an EPICS interface, but most of the subsystem level software is written in PERL. Unfortunately, the system has not been as robust as expected, and particularly, the IOC has been prone to crashes. During the last year we have made great strides in stably operating the HV system at near optimal values. While more elegant solutions are under consideration, a focus on reducing communication to the IOC has allowed much more stable operation. By communicating directly with the HV mainframe through a VT220 terminal, we were able to determine that the MuID HV could be ramped up or down in a single step without endangering the health of the Iarocci tubes. Prior to this study, the system was ramped up and down in multiple steps, each of which required issuing a command for every channel.

Another important HV issue has been stable operation of individual chains. Sparks, most likely inside the tubes, were causing frequent trips, on the order of one per minute. By exploring slightly higher trip limits for these chains, the stability was significantly increased. Basic spark protection which could lower the voltage of a badly sparking chain was added to the HV control software before the higher trip limits were implemented.

One of the more unexpected HV issues MuID has faced was a problem with some of the HV modules which caused the modules to operate at a voltage lower than the reported value. Roughly a fourth of the modules have had to be swapped out because at least one of its channels was suspected to suffer from this defect. The two layer nature of the MuID “two-packs” made this problem harder to see and diagnose.

2.4 Two-pack Efficiencies

An essential component in the evaluation of the performance of the MuID detector has been the investigation of the efficiencies of the Iarocci tubes. Of particular importance is the combined efficiency of the “OR”ed layers of the detector which form two-packs, but useful information has also been gleaned from looking at single layers. These studies
were done with cosmic ray events triggered by the "blue logic" trigger. The trigger uses no information from the gap which is analyzed in order to avoid trigger bias. Two main reasons for using this data set rather than collision data are: (1) these lower occupancy events reduce ambiguities and (2) the more uniform particle flux gives better statistics for much of the detector. The basic analysis begins by using the offline analysis package with an appropriately modified roadfinder, as discussed below, to reconstruct the events. A routine then loops over the reconstructed roads and finds the two-pack(s) in the gap of interest which the road intersects. This list of two-packs is then looped over and the raw hits are searched to see if the expected two-pack, or the one on either side, actually reported a hit. The roadfinder for this procedure is modified to exclude using vertex information and information from the plane of interest.

Some of the findings from this work so far indicate that healthy vertical two-packs operated at 4350V are roughly 95% efficient, healthy horizontal two-packs operated at 4350V are roughly 91% efficient, and two-pack efficiencies are significantly higher than $1 - (1 - c_1)(1 - c_2)$, where $c_1$ and $c_2$ are the single layer tube efficiencies. Typical panel efficiency plots are shown in Figure 3.

![Figure 3: Panel Efficiency.](image)

### 2.5 Online Monitoring

Online monitoring tools are essential for quickly verifying the basic health of the detector and validity of the data. The MuID online monitoring is constructed inside a PHENIX standard C++/ROOT based framework. Andy Glenn has contributed significantly to the current state of the MuID online monitoring. The monitoring is designed to function on two different levels. The monitoring is run interactively by a member of PHENIX shift crew, who views basic messages and figures as seen in Figure 4 to determine that the detector appears to be functioning properly. The monitoring is also run in a background mode which produces more detailed information in the form of automatically produced intranet web pages. This method has proven useful in diagnosing an unexpected failure mode. After unexpected patterns were seen by the PHENIX shift crew, a MuID expert was able to use the monitoring web pages to quickly determine that a HV mainframe had failed in a way that was extremely difficult to detect in the high voltage monitoring.

These online monitoring tools also provide a relatively low-overhead method for quick low-
level analysis of the data. This was very useful in correcting and verifying the MuID channel mapping and looking at occupancies during shielding tests.

### 2.6 Muon Mock Data Challenge

Beginning in late May of 2001 PHENIX began a concerted effort to prepare the analysis code for the data to be collected in RHIC’s second year of running. This would be the first physics data recorded for the Muon Arms. Although, most of the central arm detectors of PHENIX had at least some sectors instrumented, even these subsystems would need to modify their software for the additional instrumented sectors. The PHENIX of 2001 was a very different experiment from that of the previous run. Dave Morrison decided that a large scale mock data challenge would serve PHENIX well and named Jason Newby as the muon MDC Manager.

We began with a large scale simulation of 100,000 Au+Au collisions at 200 A-GeV using the HIJING event generator and simulating the response of the detector using the PHENIX GEANT package PISA. In addition, 20,000 Pythia 200 GeV p+p events were simulated with half requiring a $J/\psi$ to produce daughter muons within the south muon arm acceptance. We utilized computing resources at both BNL and the RIKEN facility in Japan.

In the previous run, the central arm groups had not simulated the response of their detectors by producing a file of the same format as that of the PHENIX data acquisition system which led to some surprises when the real data arrived. All detectors had new data formats for the 2001 run. We minimized any incompatibilities with offline analysis by matching the detector simulation to the planned real data formats as closely as possible. Not only did we simulate the central arm response in the real data format, but we also combined it with the Muon Arm simulated data into a single PHENIX data file.

Neither the reconstruction of simulated nor real data had ever been performed together
in a single analysis package. Any $e - \mu$ physics analysis would require the coordinated reconstruction of events in both the central arms and muon arms. We worked to combine the existing separate analysis routines into a single analysis package and tested it on the MDC simulations.

The total number of collisions for RHIC was expected to be dramatically more than the previous year. We needed to benchmark our reconstruction code for both speed and storage requirements. From our observations we were able to target areas for improvement and provide estimates for the allocation of required computing resources.

The MDC represented the successful culmination of extensive revision and enhancement of muon arm simulation software, demonstrated our ability to read and write data in the correct format, exercised use of the database for simulations, and provided a simulated data set used for testing reconstruction software and estimating reconstruction efficiencies.

2.7 MuID Offline Computing

The continued development and general maintenance of the MuID subsystem offline computing has been primarily the responsibility of the UT RHIP group. Our presence at BNL has enabled us to be the local representative to the collaboration for MuID’s computing interests. Additionally, we have been able to respond to the developing collaboration-wide computing standards by implementing these standards for the MuID subsystem.

The PHENIX analysis of the data from Run 2000 was implemented in part using the technology of ROOT macros. This interpreted code facilitated a rapid development and refinement of the reconstruction, but it soon became obvious to many of us that it was a simple solution to a small scale task that quickly became very complicated as the task grew larger in scope. A transition to a more robust, compiled reconstruction model was necessary. This technology would make available a wider range of tools for debugging and code optimization. Building on the framework already developed for the online data monitoring, we converted the Muon Arm portion of the reconstruction macros used in the muon MDC to demonstrate the conversion process and advantages of such a model.

When real data became available for the MuID, we realized that we had twice the occupancy for Au-Au minimum bias collisions that the simulations had predicted. Investigation revealed that there were two factors that were dominating this discrepancy. The end of one of RHIC's dipole magnets was located just within the last gap of the MuID. High rapidity particles were interacting with this material and shining into the detector leaking in between the absorber layers of the MuID. Since these magnets were not included in our GEANT simulation, this effect was not properly characterized. Furthermore, the algorithm responsible for the response of the detector assumed trajectories originating from the nominal vertex region. While the beam pipe material that continues through the MuID was included in the simulation, the particles that sprayed from interactions with this material were not likely to produce the correct number of MuID hits. An improvement was implemented by us by making changes in two areas. The material responsible for the scattering was included in the GEANT simulation and the offline software was modified to provide efficient response to particles originating along the beam pipe within the MuID.

A good deal of MuID software maintenance was also required. A residual analysis of the first real data revealed several inconsistencies between the ideal MuID channel mapping and
what had actually been cabled. Two types of errors were observed. The cables for many of the vertical channels had been altogether reversed and a few even had very subtle shifts by only one channel. Each inconsistency was identified through tedious bookkeeping and properly propagated to the channel mapping stored in the PHENIX database. As reconstruction of this year’s data ramped up, various bugs and memory leaks were revealed that were beyond the statistics of the muon MDC. These were identified and corrected through the collaborative effort of the PHENIX Data Production Manager and the subsystem programmers. The PHENIX collaboration decided to move away from the reconstructed data format resulting in the transition from STAF to the ROOT analysis packages. We have implemented these new structures for the MuID and guided subsystem programmers for the Muon Tracker detector. All information from the Level 2 triggers is saved with the reconstructed output as unformatted packets. We were able to contribute to the offline infrastructure by providing formatted access to these primitives. This will facilitate efficiency calculations for the muon triggers as well as the central arm triggers and refinement of these triggers for future runs.

2.8 Muon Level 2 Trigger

![Graphs showing muon trigger acceptance for the J/ψ requiring deep tracks.](image)

Figure 5: Dimuon trigger acceptance for the J/ψ requiring deep tracks are shown. The left panels show the J/ψ yields and triggers from the 1000 event simulated sample as a function of $p_T$. The sample is divided into two $x_F$ bins, the lower panels showing $x_F < 0.094$ and the upper panels showing $x_F > 0.094$. The panels on the right show the ratio of the respective distributions.
Figure 6: The dimuon trigger efficiency for the $J/\psi$ is shown as a function of MuID tube efficiency for two different sets of trigger cuts relative to the value for 100% tube efficiency. While the “Loose” set of cuts retains 18% more of the $J/\psi$ events than the “Tight” set of cuts, this demonstrates the limited dependence of the trigger on MuID tube efficiencies by using the “Loose” cuts.

Table 1: Level 2 Rejection Factors for real Au-Au 200A-GeV collisions.

<table>
<thead>
<tr>
<th>Level 2 Algorithm</th>
<th>Rejection Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimuon</td>
<td>47</td>
</tr>
<tr>
<td>Dimuon Peripheral</td>
<td>3000</td>
</tr>
<tr>
<td>Single Muon</td>
<td>7</td>
</tr>
<tr>
<td>Single Muon Peripheral</td>
<td>120</td>
</tr>
</tbody>
</table>

The south muon arm of PHENIX was fully instrumented for the 2001 heavy-ion run. One of the primary physics topics for this run was $J/\psi$ production. All collisions could not be written to tape, so we needed a trigger to enhance this rare-event signal. With an expected Level 1 trigger rate of 1400 Hz, we would only be able to write events at 80 Hz. Furthermore, the muon arm would only be allocated 40% of this bandwidth, 75% of which to be given to the dimuon trigger. Therefore, a dimuon trigger was needed which would accept no more than one in 58 events and make this decision in less than ten milliseconds. As is characteristic of rare-event triggers, we would need to balance the demand for high
rejection with that of good signal efficiency.

A Level 1 trigger was already under development for the muon arm that utilized a very simple track finding algorithm on the five planes of the MuID. This trigger was designed to be able to provide these tracking primitives to the subsequent Level 2 trigger. Unfortunately, the ISU Level 1 trigger was not ready in time for the 2001 run. We recognized this sufficiently far in advance that we were able to have a back-up trigger in place for the run, a CAMAC and NIM-based "Blue Logic Trigger." We refined the algorithm that had been designed for the limitations of Level 1 hardware, and ported that code to the Level 2 framework. This had the advantage that it had already been optimized for speed and already been somewhat tested. The MuID detector is comprised of five planes perpendicular to the beam axis each with six panels each with Iarocci tubes oriented both vertically and horizontally. In Level 1, two-dimensional tracks are found by analyzing a set of tubes collected symmetrically about a straight-line projection from the vertex to each tube in the first MuID plane. The algorithm use dynamic steering to facilitates track-finding for roads suffering multiple scattering. Individual tube inefficiencies are compensated by allowing skipped planes. The Level 1 algorithm tracks a particle through the detector by OR’ing the tubes within each plane in such a way that a particle traveling at an angle that begins in one panel but transitions to another panel in subsequent planes can still be tracked. This part of the algorithm prevented the trigger from providing enough rejection. So, we altered the algorithm to treat each panel independently and then made a slight modification to accomodate the most likely transitions. The result of this algorithm is a list of tracks in each orientation and the depth into the detector for which each was tracked.

In Level 2 these two-dimensional tracks are combined to form three-dimensional tracks. Not all of the particles that produce hits in the MuID detector come from the vertex. In fact, a significant background was caused by high rapidity vertex particles that interacted with the beam pipe within the MuID. These drastically reduce the rejection of the trigger using one orientation (horizontal or vertical tubes). By requiring some consistency between the tracks in both orientations we were able to remove some of this background. For the 2001 heavy-ion run, we used three triggers, a single muon peripheral trigger, a dimuon trigger, and a dimuon peripheral trigger. The three-dimensional tracks were used along with a centrality calculation for the single muon peripheral trigger. The trigger required at least one track that penetrated all five planes of the MuID. Any track that was within 12° of the beam axis would be outside the acceptance of the Muon Tracker and was excluded from satisfying the trigger. This also reduced the trigger rate due to hits from particles traveling perpendicular to the beam pipe. The dimuon and dimuon peripheral triggers analyze combinations of these tracks and require the dimuon opening angle to be at least 20°.

Since no real data was yet available for the South Muon Arm during the trigger development period, we trained the trigger on simulated data, 1000 minimum bias Hijing events for rejection estimates and 1000 pythia J/$\psi$ events for efficiency estimates. Figure 5 demonstrates the loss in acceptance when requiring that both daughter muons penetrate the last plane of the MuID. There is a total loss of 11% compared to requiring only one of the muons to reach the last plane, but no significant bias in $p_T$ is observed. However, since it is less likely for both daughter muons of a low $x_F$ J/$\psi$ to penetrate the full detector, 14% of this loss is in $x_F < 0.094$ and 7% for $x_F > 0.094$. Another factor driving the optimization of the various trigger parameters was the desire to minimize the dependence of the trigger efficiency on the individual MuID tube efficiencies that could vary across the detector. By
varying trigger cuts on the number of skipped gaps and requiring consistency between tracks of different orientations, we were able to limit this dependence as shown in Figure 6. As real data became available a shielding plan was implemented to stop the then-recognized beam-induced background. We removed the small MuID panels located above the beam pipe (one per gap) from the trigger because these panels could not be shielded. As a result, 25% of the J/ψ’s that would otherwise produce triggers were lost.

While good efficiency is required for a rare-event trigger, a critical figure of merit is its rejection factor which is simply the ratio of the number of events analyzed to the number accepted by the trigger. The 2001 run shielding configuration and beam conditions did not permit us to use the single muon trigger. Table 1 shows that the single muon rejection factor was much less than the required value of 58. However, by only evaluating the 60% most peripheral events, the peripheral single muon trigger could be used. The dimuon trigger rejection was marginal, but as the run conditions developed no scale down was ever required. Therefore, while the dimuon peripheral trigger was also enabled, it was redundant with the minimum bias dimuon trigger. In summary, the level 2 muon triggers provided PHENIX with the necessary rejection to meet the physics goals of the 2001 heavy-ion run.

2.9 Shielding Study

By studying simulated Au+Au collisions, we observed that a large number of particles producing hits in the Muon Identifier were originating from the beam-pipe. After obtaining the first values of the rejection factor for the real data, it was decided to add shielding in the square hole of the MuID in order to eliminate the particles coming from the beam-pipe and the DX magnet.

To determine the most appropriate shielding we had to improve the simulation in order to reproduce as much as possible the real data since, when comparing to the real data, the simulated hit rate was underestimated by a factor 2.0-2.5. The main improvements implemented in the MuID simulation package were: a) to consider the 3D momentum of the particles to determine the PISA hit locations in the MuID (whereas before all the particles were taken with a momentum parallel to the beam axis), b) to allow multiple hits for one particle in different tubes, and c) to increase the sensitive volume which determines the struck tubes. The comparison of the numbers of hits per gap and per event obtained from the the improved simulation and the real data correspond to the circles and squares tagged “No Shielding” in Figure 7.

We were then able to study the background from the particles created in the beam-pipe and DX magnet and to benchmark the performance of various potential shielding configurations. To go farther in the study of the origin of the particles firing the MuID, we followed their ancestry to the PISA input and observed that only a small fraction of the particles producing a hit in the MuID come from the MuID intended acceptance volume. On the contrary, it was observed that 80% of the primaries hit the beam-pipe in the square hole. Then, either particles produced in the beam-pipe (or the DX magnet) or their daughters created in the MuID sensitive volume fire the Iarocci tubes.

To estimate the optimal thickness of the shielding, we first looked at the momentum distribution of the particles for which a hit had been recorded in the MuID and which was created in the beam-pipe region or the DX magnet region. From our simulation, one inch of aluminium should eliminate 75% of the electrons and positrons but would reduce by only
approximately 5% the numbers of pions and by 41% the number of protons hitting the MuID. The difference between 3 and 6 inches of iron shielding is mainly a reduction in the number of pions by 33% and 64%, respectively. The background could be further reduced by installing even more shielding; however, 6 inches of iron pushed the limit of practicality for this year’s run.

To determine the best configuration of the shielding (thickness, geometry...), we did in situ tests using real data with different amounts of shielding installed in gap 4 (the last gap) and gap 3. We observed that 2 inches and 6 inches of iron reduce the panel 4 hit rate by 58% and 33% of its pre-shielding value, respectively. So, to effectively shield particles of different types (mainly electrons, pions and protons) coming from the beam-pipe and hitting the MuID, 6 inches of iron was considered a good solution.

To confirm this and to determine what would be the optimal geometry, two shielding options were simulated and studied: a) a continuous shielding in the floor and the sides of gaps 1 to 4 with 6 inches of iron and b) a continuous shielding in the floor and columns (to shield only the panels and not the absorbers of the MuID) on the sides of gaps 1 to 4 with 6 inches of iron. The number of hits in the MuID for the 4 shielded gaps (1, 2, 3 and 4) and the 5 shielded panels (all panels except the upper small panel, panel 1) is reduced by 40% with the column side shielding and by 49% with the continuous shielding compared to the configuration with no shielding. Consequently it was decided to install the shielding with the continuous sides. The installation was performed in October 2001.

The occupancy per gap obtained with the iron shielding is presented in Figure 7 and is compared to the simulations and to the configuration without shielding. We observe that the occupancy for the shielded panels (i.e. all gaps except gap 0 and all panels except panel 1) has been reduced by 5%, 23%, 63% and 58% for gaps 1, 2, 3 and 4, respectively.

The comparison of the rejection factors obtained for different triggers before and after the iron shielding was installed are listed in Table 2, where also are shown the specifications of the triggers. The values of the rejection factor are calculated masking panel 1 (i.e., we do not consider data coming from this panel for the trigger) of each gap as this panel is not shielded.
Table 2: Measured rejection factors obtained for the different dimuon and single muon triggers before the shielding (i.e. with no shielding) and after installing the iron shielding.

<table>
<thead>
<tr>
<th>Trigger name</th>
<th>Minimum angle</th>
<th>Centrality</th>
<th>Opening angle</th>
<th>RF before</th>
<th>RF after</th>
</tr>
</thead>
<tbody>
<tr>
<td>DiMuon</td>
<td>12°</td>
<td>0-100 %</td>
<td>19°</td>
<td>6</td>
<td>44</td>
</tr>
<tr>
<td>DiMuonPeripheral</td>
<td>12°</td>
<td>40-100 %</td>
<td>19°</td>
<td>62</td>
<td>571</td>
</tr>
<tr>
<td>SingleMuon</td>
<td>12°</td>
<td>0-100 %</td>
<td>19°</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>SingleMuonPeripheral</td>
<td>12°</td>
<td>40-100 %</td>
<td>19°</td>
<td>12</td>
<td>56</td>
</tr>
</tbody>
</table>

From Table 2 we see a considerable improvement of the rejection factor for the dimuon trigger. It is better of a factor 7 for the minimum bias events and of a factor 9 for the peripheral events. The rejection factors before shielding were so low that they were essentially useless. In order to fit into our bandwidth budget, we would have needed to scale them down by roughly a factor 10.
3 Publications and Talks

3.1 Refereed Publications


9. BNL E910 Collab., I. Chemakin et al., “Inclusive Soft Pion Production from 12.3 and 17.5 GeV/c Protons on Be, Cu and Au”, accepted by Phys. Rev. C.

3.2 Talks or Invited Participation


4 Financial Issues

The proposed budget for 2002 - 2003 is contained in the renewal proposal submitted to DOE simultaneously with this progress report.

We started out this fiscal year with a fairly large surplus of $40k because we had been without a post-doc for approximately 6 months and our students were not stationed at BNL until October 2000. Since we had foreseen this surplus, we decided to have two post-docs at BNL during 2001-2002. As a result of having 2 post-docs and 2 students stationed at BNL, we will completely have used up this surplus. Our best budget forecast indicates that we will be very close to breaking even at the end of this fiscal period, May 31, 2002.