Spectra/High-P_T PWG FY2k Beam Usage Request

"Complete Response," March 29, 1999.

1 Physics Goals

The Spectra/High-P_T PWG[1] is concerned with all aspects of the detector and global particle identification, and the measurement of integrated cross-sections and (y,P_T) distributions for each identified particle out to the largest possible values. The measurement of multiplicities (and ratios) and differential quantities such as dN/dy and dN/dP_T for identified particles can be cast under certain assumptions into chemical potentials, entropies, energy densities, "net-particle" densities, temperatures and flow velocities. Also of interest to the group are the high-P_T observables of angular correlations between hadrons, and the characteristics of jets that may be observable in low-multiplicity peripheral Au+Au reactions. These observables may provide additional insight into the energy-loss of fast partons as they pass through the excited system.

The particles of interest include charged$^\pm$, $\pi^\pm$, $K^\pm$, p, $\bar{p}$, d, $\bar{d}$, $\bar{t}$,[2] $e^\pm$, and γ particles. Given the emphasis on PID, the Spectra PWG is also aimed at the reconstruction of very short lived particles such as the π^0, ρ, ϕ,[3] and Ψ mesons.is also Low transverse momentum particles may carry signatures of Bose-Einstein or Disordered Chiral condensates. Exotica may be apparent as "strange" values of specific energy loss for their momentum. Of these topics, only the reconstruction and analysis of Ψ mesons does not appear to be feasible in Year 1, given the low production rate and branching fraction into electrons, the projected absence of the L3 trigger, and the relatively small EMC patch.

Typically, the minimum event sample sizes needed to perform such analyses are quite small, [1] only ~10-50k events (depending on the production rates) are needed to reasonably measure such observables for pion, Kaon, and proton particles and their antiparticles. At a rate of 1 Hz, 50k events are collected every 14 hours of beam. Thus, the goal of measuring $\pi^\pm$, $K^\pm$, p, and $\bar{p}$ spectra out to moderate P_T does not drive any discussion of the beam usage if we are trying to schedule the beam in any any unit longer than a week. This also implies the primary focus of the group's analyses will center on the study of the dependence of the spectra, and the physical quantities inferred from the spectra, as a function of global observables such as the centrality and all those defined by the EbyE PWG. Assuming 1M Au+Au events, one could extract the multiplicities and spectra for a particular particle in each of a total of 20-100 bins (again depending on the rates) in some N-dimensional space defined by each of N centrality and EbyE observables. Performing these types of analyses

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[1] Here simply "Spectra."

[2] The identification of primary tritons in STAR appears hopeless at this point.

[3] The reconstruction of ϕ mesons, as well as charged Kaon spectra, are also of interest to the Strangeness PWG.

on for $\pi^{\pm}$, $K^{\pm}$, p, and $\bar{p}$ particles comprises the bulk of the goals of the group in Year-1 data.

The analysis goals of the group are thus to form and interpret the following observables versus the centrality and other event by event variables in as many bins of these variables supported by the size of the available data sets.

1. $dN_{chgd}/d\eta$ and dN_{chgd}/dP_T
2. $d\sigma/dE_T$
3. Ratios of integrated particle rates, *e.g.* π^+/π^-, K^+/K^-, K/π, $p/\bar{p}$, and so on.
4. dN_x/dy and dN_x/dP_T, where "x" is $\pi^{\pm}$, $K^{\pm}$, p, and $\bar{p}$.

Even extremely conservative assumptions for the duty factors of STAR and the machine lead to the conclusion that all of these analyses can be performed reasonably with data from the first month or two of running. Indeed, even a few day's worth of good data from the coming summer run could support a rather detailed analysis of inclusive charged particle spectra. Even in such a simple observable do the present models differ dramatically.

Spectra analyses other than the ones above require somewhat larger data sets and hence *can* drive aspects of the beam planning. For each of these, described below, we make simple estimates for the event sample sizes that are needed. As STAR intends on triggering only on centrality in Year 1, it is reasonable to discuss these minimum sample sizes in terms of total numbers of events rather than integrated luminosities.

1.1 High-P_T Charged Particles

Based on Hijing P_T distributions for central Au+Au collisions, it is estimated a charged particle with P_T>7 GeV occurs every ~10k events, or ~10 per day of RHIC running at 1 Hz (see also section 5 below). Spectra out to high transverse momenta with direct particle identification are provided over ~$1/50^{th}$ of the cylindrical area of the TPC by the RICH detector. In order to obtain statistically significant spectra for the PID range accessible via the RICH, especially for proton and antiproton spectra, about 1M events are needed, [2] or 1 month of running at a duty factor of 1/3.

Given in addition a minimum bias p+p data set at 100 GeV/N/beam (more on this in section 5 below), the ratio of charged particle P_T spectra in central ^{197}Au+^{197}Au at $\sqrt{s}$=200 GeV/N to that in p+p collisions, normalized by the total number of binary nucleon-nucleon collisions in central Au+Au collisions, is a rather interesting observable. Predictions are shown in the right frame of Figure 1. Above P_T~4 GeV/c this ratio is extremely sensitive to the amount of partonic energy loss in the nuclear environment, in principle allowing inferences regarding the character of this environment (*i.e.* hadronic *vs.* partonic). While the results from UA1 and UA2 provide valuable references, they are by no means complete. Any analysis beyond the (ratio of) simple P_T singles spectra of charged hadrons shown in Fig. 1 must be done by us. A good example is the high P_T hadron correlation studies (discussed below) that we will do in ^{197}Au+^{197}Au which must be calibrated by "our own" p+p data.

1.2 π^0's

The identification of these particles in STAR typically requires that they have relatively large transverse momenta, which limits the rates. Shown in Fig. 2 is the inclusive P_T

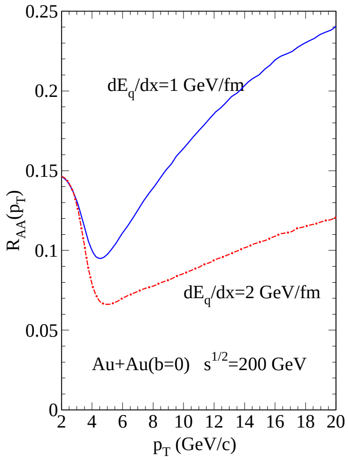

Figure 1: The ratio of charged particle P_T spectra in central ^{197}Au+^{197}Au at $\sqrt{s}$=200 GeV/N to that in p+p collisions, normalized by the total number of binary nucleon-nucleon collisions in central ^{197}Au+^{197}Au collisions, from Ref.[15].

distribution for direct photons as compared to that for π^0's with and without parton energy loss in central ^{197}Au+^{197}Au at $\sqrt{s}$=200 GeV/N. For this plot, a parton dE/dx of 1 GeV/fm and mean free path of 1 cm were assumed. [15]

Simulations on π^0 reconstruction in the BEMC/BSMD have been performed [3] using a 10% EMC patch in central ^{197}Au+^{197}Au at $\sqrt{s}$=200 GeV/N. For π^0 transverse momenta above ~1 GeV/c there is clearly the appearance of the π^0 peak in the diphoton invariant mass spectra. At transverse momenta near and above ~5 GeV/c, there is not a significant background under the π^0 peak. Analyses of π^0's out to on the order of 5 GeV/c will be feasible given ~1-2 months of central collision data near the end of Year 1 (see also section 5.)

1.3 Jets

Jets can be measured directly with the traditional jet-finding techniques developed at p+p colliders. However, according to simulations [5] these techniques break down when the multiplicities become large. For central Si+Si collisions at $\sqrt{s}$=200 GeV/N, the simulations indicate a ~60%(30%) efficiency(resolution) for finding 30 GeV/c jets using a modified-UA1 approach, while for central Fe+Fe at the same energy, the results worsen to 45%(40%). Traditional jet-finding in central Au+Au is thus completely out of the question.

However, singles spectra at high-P_T and correlations of two high-P_T particles in single events can retain a sensitivity to jet phenomena even in high-multiplicity events. [6] We would apply traditional jet finding algorithms in peripheral Au+Au collisions and attempt to correlate these results to those from the singles spectra at high-P_T, and two high-P_T particle correlations, both as a function of the total multiplicity. Such analyses would be possible given on the order of 1M minimum bias events, [4] or ~10 days of minimum bias running at 1 Hz. Assuming an overall duty factor of 33%, this takes one month of real time. A more detailed discussion and rate estimates for singles P_T spectra at high-P_T are given in section 5 below.

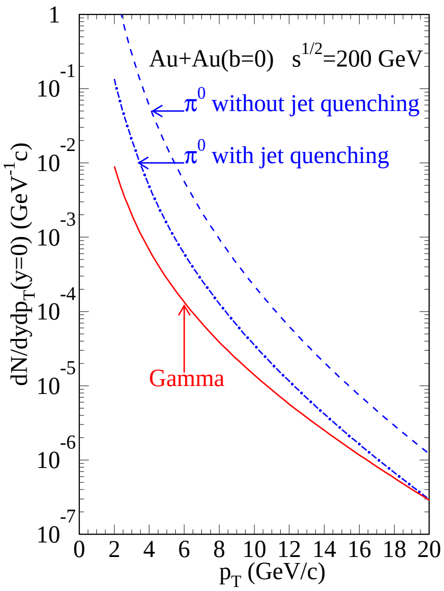

Figure 2: The inclusive P_T distribution for direct photons as compared to that for π^0's with and without parton energy loss in central ^{197}Au+^{197}Au at $\sqrt{s}$=200 GeV/N, taken from Ref. [15].

1.4 Fragments

Shown in Fig. 3 are the predictions for the rapidity and transverse momentum distributions for deuterons (left two frames) and antideuterons (right two frames) in central RQMD 2.4 events using a coalescence afterburner. On the order on 0.1 deuterons per unit rapidity at mid-rapidity in central collisions is predicted in this approach. [7, 8] While this sounds like an large rate (~8600 per 24 hours of beam), the effective rate is reduced due to a factor of ~100 background from secondary evaporation deuterons. The d production vertices in gstar simulations of Hijing events (which do not contain d's initially) indicate [9] that the primary background is π+Be→Be*→X+d, although other materials in the experiment also produce secondary deuterons.

With cuts on the distance of closest (DCA) approach of the deuteron track candidate to the primary vertex, the deuteron Signal/Background ratio can be improved considerably. [9] Using DCA cuts of 1cm in the R direction and 1cm in the Z direction (each $\sim 2\sigma$ cuts), 92 deuterons are reconstructed and pass these DCA cuts in 737 central Hijing events. This gives ~0.12 "primary-like" background deuterons per central event, and a deuteron S/B near one (integrated over all P_T), after the $2\times 2\sigma$ DCA cuts.

The red points in the second frame of Fig. 3 depict the rates per event for these primary-like background deuterons versus the deuteron transverse momentum. As the background d rates were taken after running Hijing events, while the "signal" d's were obtained from RQMD events, the background d rate is scaled downward by 30% so that this comparison is at the same total multiplicity per central event.[4] The background d rate is also multiplied by a factor of two to account for the different rapidity ranges used in each case. Given the

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[4] We have assumed that the rate for the primary-like background deuterons scales with the total particle multiplicity per event, even though we know the rates for the primary deuterons are more closely related to the multiplicity of nucleons per event.

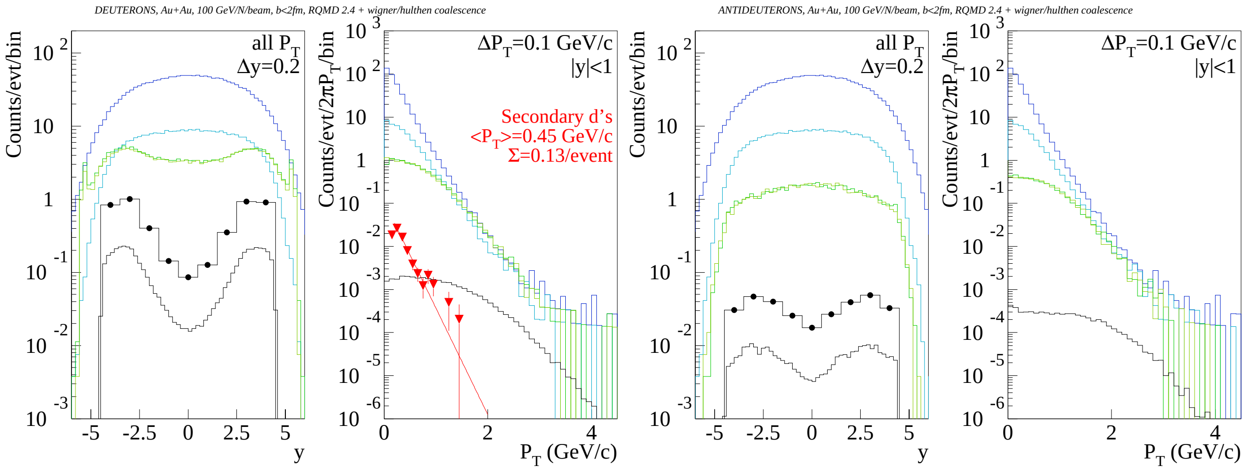

Figure 3: The light hadron, d, and $\bar{\mathrm{d}}$ spectra in central 100 GeV/N/beam ^{197}Au+^{197}Au collisions according to RQMD 2.4 and wigner/hulthen coalescence. The various lines in the two left(right) frames correspond to, going from top to bottom, $\pi^+(\pi^-)$, $\mathrm{K}^+(\mathrm{K}^-)$, nucleons(antinucleons), and finally the d($\bar{\mathrm{d}}$), which on the two rapidity plots are shown for convenience with two bin sizes, Δy=0.2 and Δy=1.

need to apply such correction factors for this comparison, the red points for the primary-like background d's should thus be taken qualitatively, *i.e.* to a factor of two or so.

The background deuterons are considerably softer than the primary (*a.k.a.* coalesced) deuterons. The mean transverse momentum of the primary-like background deuterons is ∼0.45 GeV/c, while for primary deuterons it is ∼1.5 GeV/c. Hence, the S/B increases from effectively zero to large values with increasing deuteron momentum. According to the comparison of the red points and the solid black histogram in this frame, the deuteron S/B begins to exceed unity as the deuteron momentum rises above $\mathrm{P_T}\sim1$ GeV/c. To collect 10k deuterons per unit rapidity with $\mathrm{P_T} > \sim1.5$ GeV/c (*i.e.* the deuteron $\langle \mathrm{P_T} \rangle$) would require $\sim 2\times 10\mathrm{k}/0.1 = 0.2\mathrm{M}$ central events.

Such an evaporation background does not exist for antideuterons, and hence this measurement should be relatively much cleaner. The ratio d/$\bar{\mathrm{d}}$ in central collisions is on the order of ∼5 according to RQMD 2.4. From Fig. 3 the prediction is 0.02 $\bar{\mathrm{d}}$'s per central event per unit rapidity, so collecting 10k $\bar{\mathrm{d}}$'s per unit rapidity requires $10\mathrm{k}/0.02 = 0.5\mathrm{M}$ central events.

The left frame of figure 4 depicts the impact parameter dependence of the rates/event for d's and $\bar{\mathrm{d}}$'s per unit rapidity at mid-rapidity. The rates fall approximately linearly with increasing impact parameter out to 8-10 fm, at which point they drop off more rapidly (not visible on Fig. 4's linear scale). The solid black lines in the left frame are simply linear fits to guide the eye. The d rates per event fall much more rapidly with increasing impact parameter than do the $\bar{\mathrm{d}}$ rates, as also seen in the ratio d/$\bar{\mathrm{d}}$ shown in the right frame of Fig. 4. Taking 0.035/2(0.008) as the effective rate for d's($\bar{\mathrm{d}}$'s) per unit rapidity in b∼7fm collisions implies the collection of 10k d's($\bar{\mathrm{d}}$'s) per unit rapidity at b=7fm requires ∼0.6M(1.25M) mid-central events.

Anti-triton measurements are possible in principle, although unlikely in year 1 data. There is no evaporation background, but the d/t ratio is on the order of 1000. [7] Thus, collecting 20 $\bar{\mathrm{t}}$'s per unit rapidity requires 20/(1000*0.02) ∼ 1M central events. This mea-

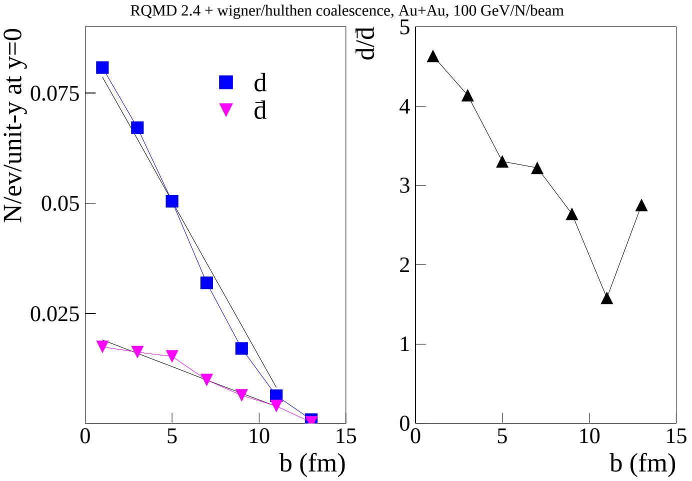

Figure 4: In the left frame, the impact parameter dependence of the production per event of primary d's and $\bar{\mathrm{d}}$'s, and in the right frame, the same dependence of the ratio of rates, $\mathrm{d}/\bar{\mathrm{d}}$.

surement would be much better done using an L3 trigger.

2 Technical data sets

Particular data sets are necessary to understand the details of the detector response. While the following requests are more related to STAR's configuration than the beams in the ring, they require setup and running time, and beam, and hence should be considered in the overall plan.

2.1 Magnetic Field

1. **Full field** - This is both the default and the maximum value, leading to the best possible momentum resolution at large transverse momenta.

2. **Half field** - Simulations indicate the low-momentum cutoff for TPC tracking is reduced by $\sim$50 MeV/c with 50% reduction in the magnetic field. This is depicted from an old simulation [10] in Fig. 5. This data thus improves our understanding of the tracking at low momenta, and possibly improves the sensitivity of DCC and BEC analyses.

   We thus request that at least 100k minimum bias events be collected at half-field to extend to lower momenta the acceptance of the TPC and for studies of the low-momentum performance of the tracking. As such a sample contains $\sim$10k central events, it would be feasible to search in this sample for the possibly exotic effects predicted at low-$\mathrm{P_T}$ from BECs and DCCs.

3. **Zero field** - These data are needed to provide additional information on detector element alignment. We know of no hard estimates, but we would assume only some thousands of minimum bias events are necessary for such studies. In principle such runs would be regularly scheduled during the run to allow diagnostics on the alignment and the means to study its evolution with time.

4. **"Opposite" fields -** These allow important tests of the reconstruction, analysis, and corrections algorithms, as observables must be independent of the magnetic polarity. The earliest goal of such running should be to fully understand the reconstruction and analysis of the light hadrons, in which case a minimum of ~100k events taken with opposite full field would be sufficient. Opposite half-field running would similarly be necessary to compare to data taken during half-field normal polarity running.

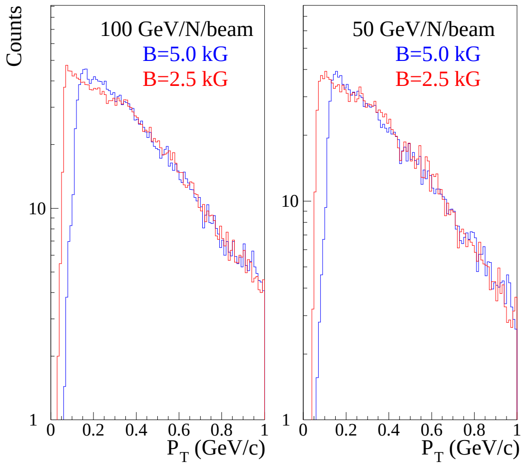

Figure 5: A comparison of TPC-reconstructed transverse momentum distributions in 100 GeV/N/beam (left frame) and 50 GeV/N/beam (right frame) central ^{197}Au+^{197}Au Hijing collisions at full field (blue) and half field (red).

2.2 TPC gas gain

The default TPC gas gain is optimized for sensitive dE/dx of pions, Kaons, and protons. The much larger specific ionization caused by fragments at low momenta can result in overflow values of the ADCs used to measure TPC dE/dx. According to simulations, the lowest deuteron momentum for which the TPC dE/dx does not overflow its ADCs is ~400 MeV/c. Higher low-momentum cutoffs for fragment dE/dx exist for mass three particles. Reducing the TPC gas gain reduces this low momentum cutoff for fragment PID from TPC dE/dx.

2.3 Trigger

Once allowed by sufficient luminosity, the use of ~3 appropriately downscaled centrality triggers is requested.

Information related to the centrality is provided by the CTB, the MWC, the EMC, and the ZDC. The information obtained from the ZDC is related to the centrality primarily by the collision geometry, while the information from the other three detectors arises from both the collision geometry and the stochastic nature of the evolution of the participant region. To understand the relationships between the detector information and the centrality, the number of participants, and so on, it important to collect on the order of 100k minimum bias events in which all four detectors are live and in the data stream. This allows one to understand the relationships between the information from the various centrality detectors in data unbiased by trigger thresholds.

Such minimum bias runs should be regularly scheduled throughout the run for this purpose. The questions as to the centrality thresholds depends on many time-dependent factors such as the luminosity and bandwidth, and hence is an issue to be revisited often throughout the running period. From our perspective, the points to keep in mind are the following. While the rate of large impact parameter collisions is large, the rate per event for pions, Kaons, and protons at mid-rapidity is relatively small. Thus, more peripheral events are needed than mid-central events to produce spectra at large impact parameters. While particle production rates are the highest for the most central collisions, the rate for events at small impact parameters is the smallest. Thus, one needs more central events than mid-central events to produce spectra at the smallest impact parameters.

2.4 "Target Out" Running and Luminosity

In order to make a correct total cross section measurement and calibrate our trigger observables, we will need a "target out" measurement to estimate the beam-gas backgrounds in particular spectra. The best way [13] to measure the beam-gas background is to use the bunch crossings where one bunch has particles in the RF bucket and the other does not. To allow time for the kicker magnets that are used to abort the beam to energize, there is approximately four RF buckets in each ring that will not be filled. There needs to be $\sim 1\mu$s gaps without any beam, so the number of empty buckets depends on how many are filled. For the nominal Au+Au running, with ~210 ns between filled bunches, this will in Year-1 leave empty many buckets that would normally be filled.

We therefore will have available in Year-1 a relatively high rate of beam-gas crossings going both directions through our beam pipe. There is a fill pattern that is made available to STAR via a RHIC module that sits in our DAQ room that can be used to select beam-beam crossings, beam-empty crossings, and, for only one experiment on a given fill, empty-empty crossings.

The current in the machine is measured using the same capacitive strips that are used to measure the position of the beam within the beam pipe. This current can be measured very precisely in the heavy ion program. Also, the charge (and hence the number of beam particles) can also be measured fairly accurately on a bunch by bunch basis by synchronizing on one bunch and measuring it a number of times, then switching to another bunch, and so on. The accuracy of these charge measurements decreases as the charge of the beam particles decreases.

Such "target out" issues become less and less of a problem as the mass of the beams increases. The primary reason for this decrease is that the beam-gas interactions become more and more asymmetric (beam-gas means primarily beam-Nitrogen or beam-Hydrogen) and the kinematic focussing throws most of the particles from these reactions downstream.

Thus, the dominant source of uncertainty in any absolute cross section measurement is not expected to be in the machine current or in the rate for beam-gas backgrounds. Rather it will be in the luminosity measurement, which will depend rather strongly on the time. This is done via the measurement of the rate for a manifestly known cross section, *e.g.* that for single-neutron removal via Coulomb excitation as measured in the ZDC. As the cross sections for this process are measured in kbarn, and as the nuclear Coulomb barrier suppresses the evaporation of all but neutrons, the rate for this process in the ZDC is immense in ^{197}Au+^{197}Au. The electromagnetic dissociation cross section needed calculate luminosoties is obtained using established techniques, [18] and should be expected to be accurate to near or better than ~10%.

For whatever physical process is chosen for the luminosity calculation, a measurement of this count rate over few minute intervals in the STAR scalers gives the needed information. In p+p, p+A, and ^{28}Si+^{28}Si, the use of electromagnetic dissociation to provide the calibration count rate is dubious. Different approaches to the luminosity calculation are needed for these beams.

3 Alternate Beam Species and Energies

Most of the Year 1 goals of the Spectra PWG can be accomplished given a total of a month or two of full energy ^{197}Au+^{197}Au data in Year 1. Hence spectra requests at least one alternate beam be run over a period long enough to result in ~1M minimum bias events, and ~1M events under some centrality condition(s). Such samples would support rather complete studies of all of the topics discussed above. If the livetime of STAR and the machine is 2/3, it would take one month of running at 1 Hz to collect these data.

The species/energy combinations most espoused in discussions that have occurred in the Spectra PWG are the following (listed in no particular order):

1. **RHIC Mode A: ~20 GeV/N/beam ^{197}Au+^{197}Au**
   These data are needed to form "excitation functions" of particular spectra versus the total CM energy, $\sqrt{s}$, from 200 & ~40 GeV/N at RHIC (Au+Au), 17 & 10 GeV/N from the SpS (Pb+Pb), and 2-5 GeV/N at the AGS (Au+Au). Perhaps more importantly though, such low energy ^{197}Au+^{197}Au beams are the closest path to direct comparisons of RHIC spectra to those measured with ^{208}Pb beams at the SpS. Such direct comparisons will be extremely important if "unusual" effects are seen during the full energy ^{197}Au+^{197}Au running.

2. **RHIC Mode B: 100 GeV/N/beam a+a, where a~^{28}Si**
   Like the full energy ^{197}Au+^{197}Au beams, these are entirely new to the field, and form a baseline for Au+Au reactions at 100 GeV/N/beam where in principle effects due to large-scale plasma formation are weak or non-existent. Perturbative effects such as quenching and shadowing should be markedly reduced given the smaller overall size of the system, and hence the theory of quark propagation in these systems should be more tractable.

   The size of the excited system is more precisely controlled via the mass of the entrance channel nuclei than via the impact parameter in ^{197}Au+^{197}Au collisions. This is becuase one simply cannot measure the impact parameter directly. The "centrality" variables that we can measure (*e.g.* CTB/MWC multiplicity, the ZDC signals, the EMC $\mathrm{E_T}$, and the no. of tracks in the TPC) are imperfectly correlated with impact parameter, and in general this correlation is the best and most reliable for only the most central tail of these distributions. Mid-central measures of centrality will be especially tricky at RHIC due to the fluctuations due to minijets.

   The comparison of specific centrality observables from the full energy central a+a collisions to those in full energy mid-peripheral Au+Au collisions will indicate the appropriateness (for a given observable) of controlling the system size in Au+Au collisions via cuts on centrality observables. This is will remain an unknown issue, observable by observable, until both minimum bias full energy Au+Au and central full energy a+a data sets are in hand.

3. **RHIC Mode C: 100 GeV p + 100 GeV/N ^{197}Au**
These data provide the most direct path to understanding possible modifications of partonic structure functions in nuclear matter, and hence are the baseline for the study of such modifications in central ^{197}Au+^{197}Au collisions.

4. **RHIC Mode D: 100 GeV/N α + 100 GeV/N ^{197}Au**
Recent calculations and FNAL E745 suggest [11] the possibility of an impact parameter dependence of nuclear structure functions. E745 is a neutrino+emulsion charged current DIS experiment that classified the impact parameter on the basis of the number of grey tracks (slow protons) associated with the collision vertex.The observation was unmodified structure functions in the "peripheral" events (few grey tracks), and EMC-like modifications in the "central" events. To perform such a search in STAR, a+^{197}Au (a$\lesssim$12) reactions may be more appropriate than p+^{197}Au reactions. With a very light ion on Au, *e.g.* ^{7}Li, one has a more sensitive impact parameter measurement while still probing a small region of the nucleus. [12] The impact parameter measurement improves as the global observables typically related to the impact parameter in STAR are generally dominated by the soft particles at mid-rapidity. One reduces dramatically the large fluctuations in this soft multiplicity by going from p+^{197}Au to, *e.g.* ^{7}Li+^{197}Au. In general, p+Au reactions may be fine for impact-parameter inclusive studies of partonic structure functions, while sensitive searches for any impact parameter dependence in these quantities in STAR requires light-ion on Au running at the full energy.

5. **RHIC Mode E: 100 GeV p + 100 GeV p**
These data provide the direct measurement of the partonic structure functions in the absence of nuclear medium modifications. Also, particularly dramatic effects related to parton energy loss mechanisms have been predicted in the simple ratio of charged particle transverse momentum spectra from central Au+Au to the same from p+p scaled by the number of binary collisions in the central Au+Au collisions. See the right frame of Fig. 1 for a prediction.

To begin to form a complete picture of the physics of interest to the Spectra PWG, all five data sets above are necessary. Given what we know about the schedule and allowing for considerable contingencies in the commissioning of the machine, the RCF, and STAR, the possibility of significant running of more than one alternate beam seems remote. We must therefore choose one. In the remainder of this section, we outline, in more detail than that sketched above, the thinking that leads to the FY2k running scenario proposed in the following section.

RHIC Modes C, D, E would benefit significantly from the increased luminosity and the more complete EMC coverage available in Year 2. Asymmetric beams, *i.e.* modes C and D, are not recommended by the machine people for Year 1 as they are expected to be relatively the most difficult to tune for collisions. There was thus unanimous consensus in the group for the postponement of the asymmetric modes C and D until no earlier than Year 2. The Spin PWG is interested in p+p running in Year 1 (mode E), primarily so that machine experience for p+p collisions is developed early, but also to take a few days worth of physics data for certain comparisons to previous experiments. Should such running occur for physics in Year-1, the Spectra PWG could make good use of these data, as described in more detail in Section 5 below.

This leaves Modes A and B, where the consensus was not at all unanimous. There has been vigorous discussion in the group on which of these two choices would be the most fertile for Year 1 Spectra physics. Fourteen members of the group voiced their opinion on this specific issue, and a majority existed by roughly a 2:1 margin. However, we stress than each of these two modes has important benefits. Should the situation change in some way(s) that significantly affects the assumptions that have gone into this proposal, a reevaluation and possible modification of the running scenario we propose below will be necessary.

A major drawback of RHIC Mode A (low energy ^{197}Au+^{197}Au) is the machine performance for such beams. Gold beams are injected from the AGS to RHIC at an energy $\sim$11 GeV/N. At energies in this regime (near and below 20 GeV/N/beam), one suffers about a factor of 10 reduction in the luminosity compared to that possible with full energy beams. The second drawback is that the length of a store goes from the nominal 10 hours down to about 2 hours. It is also strongly suspected [13] that the luminosity of the beam will drop very quickly during the short length of such a beam store.

While such running is certainly possible, it appears that it would be a very inefficient mode in Year-1. According to the RHIC Conceptual Design manual, [14] the beam energies for which long ($\sim$10 hour) beam stores and reasonable luminosities are expected begins around 30 GeV/N/beam. This implies a $\sqrt{s}$ of 60 GeV/N, which is a factor of 3.5 larger than the $\sqrt{s}$ of 17 GeV/N resulting from 158 GeV/c ^{208}Pb+^{208}Pb collisions at the SpS. Even if RHIC could operate effectively at 20 GeV/N/beam, the RHIC $\sqrt{s}$ is still a factor of more than two larger than that in the highest energy SpS collisions. Overall, direct comparisons of RHIC data to SpS data for the same $\sqrt{s}$ are simply not possible. The closest one can get kinematically to the SpS from RHIC is only, at best, approximately to within a factor of 2 in $\sqrt{s}$. Such a running mode nonetheless remains of great interest in the group for the formation of "excitation functions" of the various spectra.

There are now extensive comparison data at lower energy (SPS and AGS) for heavy beams for most of the soft physics we will do in STAR in Year 1. Running ^{197}Au+^{197}Au at 50 GeV/N/beam or 20-30 GeV/N/beam will add an additional point to interpolate between these. However, unless something qualitatively new is seen in the 100 GeV/N/beam ^{197}Au+^{197}Au running, (in which case all bets are off), it is dubious that RHIC Mode A will be the most useful of the alternate beams. Rather few analyses of SPS and AGS physics focus on the development a particular observable with $\sqrt{s}$. A notable exception to this observation includes the flow analyses, done in relatively small steps over a most interesting region of 2-10 GeV/N Au on an Au fixed target done at the AGS by the BNL-AGS E895 Collaboration. In general though, attempts at strict comparisons of the data from the AGS and SpS are rare. Rather, more often the results are interpreted "internally" by comparing different collision geometries at a constant energy, *i.e.* via the variation with impact parameter and in different mass systems at the same bombarding energy, such as S+S and Pb+Pb at the SpS. The comparison of single particle spectra, for instance, are best done this way, since the underlying nucleon-nucleon production cross sections are by definition the same and the systematic differences after scaling by number of participants ("Wounded Nucleon Scaling") are attributable to nuclear effects. The scaling at RHIC will be more complicated than it is in existing experiments.

What is new at RHIC is the significant yield in nuclear collisions for calculable hard scattering processes. The argument to retain the full beam energy and change the beam species is compelling here. The effective Parton Distribution Functions will change with either a change in energy or species. With a light ion such as Si, we expect that the shadowing issues will be under greater theoretical control as compared to Au beams. The reduction in the shadowing is the only difference, aside from the (desired) change in the system volume. An attempt to study hard processes in low energy Au+Au reactions suffers from two drawbacks - the luminosity is far lower, perhaps on the order of a factor of 10 (above), and the hard scattering cross sections at a fixed $\mathrm{P_T}$ are also smaller. It is difficult to imagine performing significant studies of hard processes in RHIC Mode A during, perhaps, the month or two in which alternate beam running may be possible in Year 1. These considerations motivate the postponement of RHIC Mode A running until Year 2, when it will benefit from the increased luminosities and the increase machine experience gained during Year 1.

Yet another fact in favor of RHIC Mode B (100 GeV/N/beam a+a, where a$\sim^{28}$Si) as the alternate beam concerns aspects of the crucial characterization, event by event, of the collision geometry, *a.k.a.* the number of participants, the "centrality, and so on. The information obtained from the ZDC is related to the centrality primarily by the collision geometry, while the information from the CTB, MWC, and EMC arises from both the collision geometry and the stochastic nature of the evolution of the participant region. The allows the very real possibility that fluctuations in the dynamical evolution of the participant region can bias the centrality inferred from the CTB, MWC, and EMC.

At RHIC, a measurement of the total mass in spectator matter is not possible. The ZDC is useful for this only for b<6 fm or so for ^{197}Au+^{197}Au, which is about 20% of the geometric cross section. We will have to characterize the events using the same phase space as we are looking for a signal, namely at mid-rapidity. Thus, a far more certain assessment of a participant volume (other than that in central ^{197}Au+^{197}Au) is possible in central a+a collisions, where a<<197, as compared to the volumes inferred from (fluctuating) global observables in peripheral ^{197}Au+^{197}Au collisions.

Finally, there is the comment from T. Kirk regarding the alternate beam that "*other beam species may be requested but the difficulty in achieving the running conditions goes roughly in the sequence: AuxAu - top energies; A'xA' (A' is another nuclear species) - top energies; symmetric beams - lower energies; unsymmetric beams and species (easiest to most difficult).*"

Thus, our proposal for the alternate beam is RHIC Mode B - full energy symmetric collisions of light ions. A specific proposal for the running scenario optimal for Spectra and High-$\mathrm{P_T}$ physics, including such alternate beam running, is presented in the next section.

4 Proposed Running Scenario

Based on the discussion in the previous section, and assuming the run lasts a total of 8 months, we propose the following run plan for the first RHIC run. Clearly, the relative amount of time spent in each of the five steps below is to be determined by many "game-time" factors such as the performance of the machine, the RCF, and STAR during the actual run. Thus, it cannot be clear at this point whether the proposal below is pessimistic or optimistic, although it does seem reasonable based on what we know today. We are working now to improve the estimate of the minimum running time needed to approach the physics of hard processes during the alternate beam running.

1. Full energy central ^{197}Au+^{197}Au for the first three months. Centrality is minimum bias initially; ~3 centrality triggers with appropriate downscaling (including minimum bias) are implemented as necessitated by the luminosity and the bandwidth. If the

live time of STAR and the machine combine to be ∼25% during this period, three months of running results in a total of ∼2M full energy, primarily minimum bias, Au+Au events.

2. Switch the accelerator from full energy ^{197}Au+^{197}Au to full energy ^{28}Si+^{28}Si. Assume this takes one month.
3. Run with minimum bias and several centrality triggers for on the order of 1 month, which, assuming a STAR and machine livetime of 50% during this time, results in ∼1.25M events.
4. ∼2 weeks of p+p running, which includes both the machine studies phase and perhaps some days of physics running, would go here if it occurs.
5. Switch the accelerator back to full energy ^{197}Au+^{197}Au. Assume this takes one week.
6. Run primarily central triggers (with admixtures of minimum bias) until the end of the run, or ∼6-7 weeks. This would result in ∼2M, primarily central, events necessary to study high-P_T π^0's and other directly identified particles at high-P_T, and to allow the binning of the events into numerous categories defined EbyE to fully explore the "spectral landscape" in central events.

5 Rate Estimates for p+p and ^{28}Si+^{28}Si collisions

We have proposed full-E light-A as the primary alternate beam. The spin PWG has requested p+p running in Year 1. In either case, we would prefer that any alternate beam running occur during the middle of Year-1, presumably once the machine and detector are working well and there is already several million minimum bias and central full energy ^{197}Au+^{197}Au events on tape. As we have requested a return to the full energy ^{197}Au+^{197}Au running for 2-3 months at the end of Year-1, the rate estimates for the alternate beam(s) running must be carefully considered. Clearly, the alternate beam(s) running must be long enough to do decent analyses. It may also be that past some integrated luminosity in the alternate beam(s) running there is a lesser benefit to the kinds of analyses of interest to Spectra in Year-1. At such a time, it would be more productive overall to switch back to the full energy ^{197}Au+^{197}Au running to pursue the rarer observables and allow finer binning of the spectra versus E-by-E observables. We thus describe in this section more detailed estimates for the minimum sample sizes that would be needed for the primary Spectra analyses of RHIC Year-1 p+p and ^{28}Si+^{28}Si collisions. In either case, the physics goal which drives the event sample sizes is how far out in P_T we can reach for single hadrons.

5.1 p+p in Year-1

Shown in Figure 6 is a compilation of cross sections from the ISR, UA1 and CDF for charged hadron production at high P_T at various values of $\sqrt{s}$, taken from Ref. [15].

Using the UA1 points at 200 GeV as reasonable guidance,[5] one reads: [17] $d\sigma/dy/d^2P_T = 3\times10^{-5}$ mb/GeV^2 at 5 GeV/c, and 1×10^{-6} mb/GeV^2 at 8 GeV/c, thus $d\sigma/dy/dP_T = 10^{-3}$ mb/GeV at 5 GeV/c and 5×10^{-5} mb/GeV at 8 GeV/c.

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[5] We are at $x_T=2P_T/\sqrt{s} \sim 0.05$ for the hadron, so the parton has x∼0.1 or so, and gluons dominate in this region.

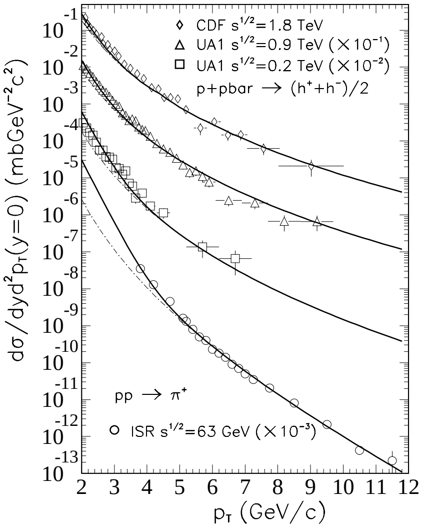

Figure 6: Experimental charged particle P_T spectra in p+p and p+$\bar{p}$ collisions as shown in Ref. [15].

If the effective luminosity for useful p+p collisions is very low in Year-1, a trigger may be necessary to reach such transverse momenta. In the absence of L-3, such a trigger cannot be based on TPC information. However, one can define the hadrons of interest as π^0's, and implement a high-P_T trigger based on EMC information, *e.g.* a “high-supertower” trigger. We assume that the phase space covered by the instrumented Year-1 EMC patch is 10% of the full azimuth[6] for 1 unit of pseudorapidity. Also, we take a RHIC Year-l p+p luminosity[7] of 10^{29}/cm^2/sec = 100/mb/sec, which implies one collects 1 count per GeV/c every 100 seconds at P_T=5 GeV/c and every 2000 seconds at P_T=8 GeV/c, or 800 and 40 counts per day, respectively. A run of a few days of 100 GeV/c/beam p+p collisions at 10^{29}/cm^2/sec, including EMC-based triggers on high-P_T π^0's, would thus yield rather nice data set out to ~8 GeV/c.

If, for whatever reason, a high-P_T π^0 trigger is not available during the p+p running, the plan would thus involve running long enough with interaction triggers to collect reasonable statisics at high-P_T. We assume one can trigger via the CTB and MWC on minimum bias p+p interactions with a cross section of about 40 mb. From the above, the cross section per unit rapidity for π^0 production at 5 GeV/c is about 10^{-3} mb/GeV, so the cross section for charged particle production will be twice that. Also, the acceptance for charged particles in the TPC will be over two units of rapidity with the full azimuthal coverage, so the cross section for charged particles in the TPC is then 4×10^{-3} mb/GeV. The number of high P_T charged particles per GeV/c at 5 GeV per minimum bias p+p event is $4\times10^{-3}/40$, or 10^{-4}. One million minimum bias p+p events would thus yield 100 counts per GeV/c at 5 GeV/c.

Perhaps it is possible to collect p+p events at a rate considerably higher than 1 Hz given the small event sizes. A data rate of 10 Hz would result in 0.8M events/day. Anywhere in this ballpark, on the order of a week of minimum bias p+p running would allow the study of charged pion transverse momentum spectra to at least 5 GeV/c. This is well into the “interesting” region for which the transverse momentum spectra are rather sensitive to the detailed nature of the parton propagation (*i.e.* the right frame of Fig. 1.)

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[6] The present projection [3] is 12-14 modules in Year-1.

[7] The design luminosity for p+p at 200 GeV is about 2×10^{30}/cm^2/sec.

The measurement of spectra with PID at high-P_T requires a significantly larger sample of p+p events. Roughly speaking, one must first divide the minimum bias p+p rates at 5 and 8 GeV/c above by roughly a factor of ~50 to account for the relative solid angle coverage of the TPC and the RICH. Second, the rates above are for both charge signs. Thus, if R_{chgd} is a minimum bias p+p rate per GeV/c at some P_T, then the identified π^+ rate at the same P_T is $\sim R_{chgd}/50/2$ (as is the identified π^- rate). Identified Kaon and proton rates at high-P_T suffer an additional factor of ~10 or more reflecting typical K/chgd and p/chgd ratios. Reaching $P_T >5$ GeV/c in identified particle spectra in Year-1 p+p running does not seem possible. However, depending on the length of the p+p run and the performance of the machine and STAR, Year-1 p+p data should be able support studies of identified spectra out to ~3 GeV/c or so. In ^{197}Au+^{197}Au, such transverse momenta are well into the transitional region between the soft and hard extremes that indicates the onset of minijet phenomena.

5.2 ^{28}Si+^{28}Si in Year-1

In the absence of nuclear effects (*i.e.* shadowing and quenching), the total cross section in A+A collisions scales as quadratically, *i.e.* $\sigma_{tot}=\sigma_{pp}A^2$. There is also the general rule that 10% of the hard cross section is contained in the 2% most central fraction of the geometric cross section. This is illustrated in Figs. 7 below, which were taken from Ref. [16]. In the right frame one sees that ~10%(40%) of the hard cross section is contained in the ~2%(10%) most central fraction of the total cross section. There is only a weak dependence of this rule of thumb on the mass of the colliding nuclei.

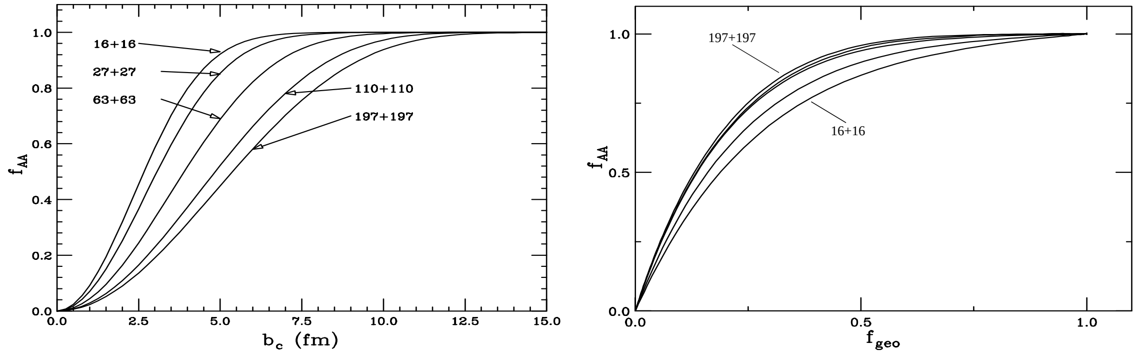

Figure 7: In the left frame, the central fraction of the hard cross section as a function of the impact parameter cut, and in the right frame, the fraction of the hard cross section as a function of the total geometrical cross section for several symmetric systems (197+197, 110+110, 63+63, 27+27, and 16+16) taken from Ref. [16].

Based on this rule, and taking the centrality cut as the 2% most central of the events, the number of hard processes per central event is $0.1\sigma_{pp}A^2/(0.02\sigma_{geo})$, where A is the mass in A+A collisions and σ_{geo} is the total geometric cross section. This quantity is, in mb, $\sigma_{geo}=10\pi(2R)^2$ given R in fm, so taking $R=(1.2\text{fm})A^{1/3}$ gives $\sigma_{geo}=181A^{2/3}$. Thus, the number of hard processes per (2%) central A+A event goes as $0.028\sigma_{pp}A^{4/3}$, where σ_{pp} is in mb.

Including the factor of 2 coming from the TPC's coverage of two units of pseudorapidity and the factor 2 from detecting both charge signs, the probability per event per GeV/c at P_T=5 GeV/c is $(0.028)(4)(10^{-3})A^{4/3}$, or 2×10^{-3}. Thus, ~50k events are needed to obtain

100 counts in a 1 GeV bin at 5 GeV/c.

At 8 GeV/c, one expects a probability per event per GeV/c of $(0.028)(4)(5\times10^{-5})A^{4/3}$, which via the values of σ_{pp} is a factor of $10^{-3}/5\times10^{-5} = 20$ lower than the rate at 5 GeV/c. Thus, ∼1M events are needed to obtain 100 counts per GeV/c at 8 GeV/c.

We note that these numbers of events change rather little if the centrality condition is relaxed to, *e.g.*, the 10% most central events. If the 2%(10%) most central collisions contain about 10%(40%) of the total hard scattering cross section, then the ratio of cross section fractions, hard/geometric, is on the order of 40/10=4 for a 10% centrality and 10/2=5 for a 2% centrality.

5.3 Cross Checks and Comments

We have also looked at p+p, ^{28}Si+^{28}Si, and ^{197}Au+^{197}Au events that were generated using Hijing. [4] The transverse momentum spectra obtained in $|\eta|<1$ are shown in Fig. 8. For three of the histograms shown in this figure, Hijing was run without quenching and shadowing, so direct comparisons with the numbers derived above is possible.

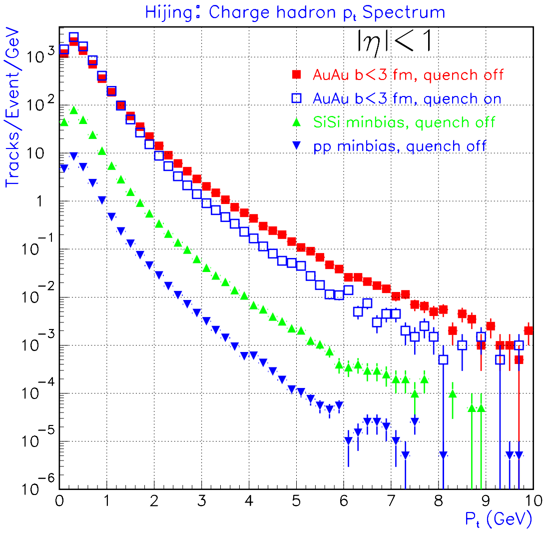

Figure 8: The transverse momentum distributions for minimum bias p+p and Si+Si collisions, and central Au+Au collisions obtained [4] from Hijing with quenching and shadowing turned off. Also shown, as labelled in the frame, are central Au+Au spectra from the same model with the default quenching enabled.

For p+p, one takes $d\sigma/dy/dP_T = 10^{-3}$ mb/GeV for hadrons at 5 GeV/c from Ref. [15], σ_{geo}=40 mb, and the factor of 2×2 for the two charge signs and the TPC's two units of rapidity coverage. This implies $4\times10^{-3}/40=10^{-4}$ charged tracks per event in a 1 GeV/c bin at P_T=5 GeV/c, as in Fig. 8. For minimum bias Si+Si, the total hard cross section is $\sigma_{AA}=A^2\sigma_{pp}$, and the geometrical cross section is $\sigma_{geom}=4\pi R^2=181A^{2/3}$ mb. Then the number of charged tracks per event per GeV/c at 5 GeV/c is $(0.028)A^{4/3}\sigma_{pp} = (0.028)85(4\times10^{-3}) \sim 1.9\times10^{-3}$, as in Fig. 8. The same logic applied to central Au+Au collisions implies the rate of charged hadrons per event per GeV/c at 5 GeV in $|\eta|<1$ should be $2.8\times10^{-2}(4\times10^{-3})(197^{4/3}) \sim 0.13$, which is also close to what is seen in in Fig. 8.

In summary of this section, the presence of an instrumented EMC and an ability to form simple triggers based on EMC information during the p+p running would dramatically extend the reach of the p+p program. It would result in significant samples of high-P_T π^0's. However, interesting physics in p+p are also possible given only an interaction trigger. At a rate of 10 Hz, approximately 0.8M p+p events per day of running are collected. A week of p+p running, even if only an interaction trigger is used, would in a substantial rates for hadrons at high-P_T.

Similar conclusions can be drawn for the ^{28}Si+^{28}Si running we have proposed. Only ~50k events from 2% central ^{28}Si+^{28}Si running are needed to obtain 100 counts in a 1 GeV bin at 5 GeV/c. This is about a half-day of running at an event rate of 1 Hz. Thus ~1 week of some mixture of central and minimum bias ^{28}Si+^{28}Si running also results in an extremely significant data set for high-P_T physics. The rates for measuring single high-P_T hadrons well into the perturbative regime are robust for modest runs of lighter ions and p+p during Year-1, even at luminosities well below design luminosity and with a small Year-1 EMC patch.

6 Spectra Rates Table

Table 1: The event sample sizes needed to reach particular count levels relevant to specific Spectra analyses in RHIC Year-1 100 GeV/beam p+p, 100 GeV/N/beam ^{28}Si+^{28}Si, and 100 GeV/N/beam ^{197}Au+^{197}Au running, as noted, under the assumptions outlined in the previous sections. This table does not include the data sets discussed in section 2.

To study:	**in:**	**requires at least:** (events/sample)
$\pi^{\pm}$, K$^{\pm}$, p, $\bar{\mathrm{p}}$ to moderate P$_\mathrm{T}$	^{197}Au+^{197}Au	0.05M
1000 h$^{\pm}$ per GeV/c at P$_\mathrm{T}$=5 GeV/c	^{197}Au+^{197}Au, central	0.01M
1000 h$^{\pm}$ trks per GeV/c at P$_\mathrm{T}$=8 GeV/c	^{197}Au+^{197}Au, central	0.2M
p, $\bar{\mathrm{p}}$ in the RICH	^{197}Au+^{197}Au, central	1M
Jets	^{197}Au+^{197}Au, min. bias	1M
10k d per unit-y with P$_\mathrm{T}$>1.5 GeV/c	^{197}Au+^{197}Au, central	0.2M
10k $\bar{\mathrm{d}}$ per unit-y, all P$_\mathrm{T}$	^{197}Au+^{197}Au, central	0.5M
20 $\bar{\mathrm{t}}$ per unit-y, all P$_\mathrm{T}$	^{197}Au+^{197}Au, central	1M
10k d per unit-y with P$_\mathrm{T}$>1.5 GeV/c	^{197}Au+^{197}Au, b~7fm	0.6M
10k $\bar{\mathrm{d}}$ per unit-y, all P$_\mathrm{T}$	^{197}Au+^{197}Au, b~7fm	1.25M
100 h$^{\pm}$ per GeV/c at P$_\mathrm{T}$=5 GeV/c	^{28}Si+^{28}Si	0.05M
100 h$^{\pm}$ per GeV/c at P$_\mathrm{T}$=8 GeV/c	^{28}Si+^{28}Si	1M
100 π^0 per GeV/c at P$_\mathrm{T}$=5 GeV/c	p+p, high-tower trigger	0.01M
100 π^0 per GeV/c at P$_\mathrm{T}$=8 GeV/c	p+p, high-tower trigger	0.2M
100 h$^{\pm}$ per GeV/c at P$_\mathrm{T}$=5 GeV/c	p+p, min. bias	1M

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