A Comprehensive Tracking Upgrade for the Solenoidal Tracker At RHIC (STAR)

The STAR Collaboration

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Executive Summary

The STAR Collaboration proposes a comprehensive upgrade of its tracking capability in preparation for the next phase of discovery physics at RHIC. Specifically, it proposes the construction of a new, next generation micro-vertex detector at mid-rapidity using a combination of monolithic active pixel sensors (MAPS) and conventional silicon strip technology and a new forward tracking detector based on cutting edge Gas Electron Multiplication (GEM) technology.

At mid-rapidity, the optimal configuration for the proposed microvertex detector has been determined to be two concentric layers of monolithic active pixel sensors surrounded by two concentric layers of silicon strips. The MAPS layers—termed the Heavy Flavor Tracker (HFT)—utilize state-of-the-art, ultra-thin active pixel sensor technology developed in collaboration with the Institute de Recherche Subatomique (IReS) (Strasbourg, France). The surrounding silicon strip layers, named the Intermediate Silicon Tracker (IST), assist the existing Time Projection Chamber (TPC) and existing Silicon Strip Detector (SSD) in accurately pointing candidate tracks back to the MAPS layers within the search radius required for efficient detection of short-lived particles containing charm and bottom quarks. The HFT design was reviewed favorably by the BNL Detector Advisory Committee in March 2006 and an aggressive research and development program was encouraged. Following the recommendations from that review, the proponents have since continued a robust program of R&D in anticipation, if approved, of a construction start in FY09.

The primary motivation for the proposed inner tracking upgrade at mid-rapidity is to extend the physics capability of STAR for the study of heavy quark production in (polarized) p+p, p+A, and A+A collisions at RHIC. Important physics questions to be addressed include the nature of the process by which partons lose energy in the dense hadronic matter produced in central heavy ion collisions, and the extent to which that matter is thermalized; as well, the spin structure of the nucleon. The proposed combination of detectors will make it possible to measure displaced vertices and to do direct topological reconstruction of open charm hadrons via their charged decay daughters. As an example, the decay $D^0 \rightarrow K^- + \pi^+$ can be identified directly by using the HFT to select K^- and π^+ tracks in STAR with a common decay-vertex that is displaced by ~100 μm from the collision-vertex. The ability to do topological reconstruction of particles containing heavy quarks is crucial since it is virtually impossible to reliably separate particles containing charm and bottom quarks via their semi-leptonic decays.

When combined with the existing STAR TPC and SSD, the HFT and IST constitute an integrated state-of-the-art mid-rapidity inner tracking system which is unique at RHIC. This tracking system will significantly extend the reach of the STAR scientific program. It will afford efficient topological reconstruction of D and B mesons down to low transverse momenta (for D's ≥ 500 MeV) illuminating their in-medium interactions and the properties of the strongly interacting quark-gluon plasma recently discovered at RHIC. When combined with the newly constructed STAR TOF barrel, the proposed detectors provide STAR entirely new capability for the detection and study of low-mass di-lepton pairs and in-medium effects on vector meson production predicted to result from partial or full chiral symmetry restoration.

At forward rapidity, the optimal configuration to achieve STAR's scientific goals includes six triple layer disks of Gas Electron Multiplication (GEM) detectors, collectively termed the Forward GEM Tracker (FGT). These detectors will afford accurate charge sign determination for electrons and positrons from $W^{\pm}$ decay, allowing a seminal study (not possible presently) of the (u, d) flavor dependence of the spin-dependent sea anti-quark distributions in the proton. Building upon the groundbreaking work at other laboratories, the technology to construct this upgrade has been developed through an aggressive program of collaborative R&D with Tech Etch Corporation, made possible by a Small Business Innovation Research (SBIR) grant.

A technically driven schedule for the construction of these detectors suggests their construction could begin in FY09 and be complete in under 3 years. The motivation to construct these detectors and produce first physics as soon as possible is extremely high given plans for 500 GeV p+p running at RHIC and the planned startup of the Large Hadron Collider (LHC). The scope of the construction for the mid-rapidity tracking system is projected to be ~ $9M FY07 dollars, including contingency. The corresponding cost to construct the Forward GEM Tracker is estimated to be ~ $2M, making the entire scope for the full suite of planned upgrades fully consistent with the projections made in the BNL Mid-Term Plan. The proposed construction projects are highly leveraged by significant contributed labor. These contributions will be provided by participating institutions from the STAR Collaboration, which are fully committed to the timely completion of these upgrades as a central and essential piece of the Collaboration's vision for its scientific future at RHIC.

The STAR Heavy Flavor Tracker (HFT)

The HFT is the central component of the mid-rapidity tracking upgrade for STAR. It is a new and innovative detector concept that will enable STAR to do direct topological reconstruction of open charm hadrons. This capability is essential because it is nearly impossible to distinguish hadrons which contain charm and beauty via their semi-leptonic decays. Only direct topological reconstruction of the daughters emitted in the hadronic decay channels uniquely identifies parent particles containing charm or beauty. The proposed detector technology to accomplish this measurement utilizes CMOS pixel arrays, named MIMOSA, being developed at the IPHC laboratory in Strasbourg, France. The silicon pixel arrays proposed for use in the STAR HFT are 5th generation MIMOSA chips. These follow earlier STAR prototypes (MIMOSTAR I-IV) developed over a period of several years.

The primary motivation for the HFT is to extend STAR's capability to measure heavy flavor production by reliable detection of displaced vertices. This is a key measurement for the ongoing and future heavy ion program at RHIC as it advances toward quantitative comparison of theory and experiment to determine the properties of the strongly interacting partonic matter discovered in heavy ion collisions at RHIC as well to a detailed understanding of the spin structure of the nucleon in polarized p + p collisions. The primary physics topics to be addressed by the HFT include the spectra and yields of open charm measurements in p+p, p+A, and A+A collisions; the extent to which heavy quarks experience energy loss and collective flow in central heavy ion collisions, and, correspondingly, the extent to which the produced matter through which heavy quarks pass in heavy ion collisions is thermalized.

One of the most exciting new capabilities provided by the proposed HFT is measurement of the elliptic flow of D mesons down to low p_T ($\geq$ 500 MeV/c). It is generally believed that the elliptic flow of hadrons observed in the final state of relativistic heavy ion collisions is very likely established in the early stage of the collision when the relevant degrees of freedom are still those of deconfined partons. If particles containing charm quarks (which have a mass ~ 1.5 GeV/c significantly greater than the initial temperature of the system ~ 300-500 MeV/c) demonstrate significant elliptic flow, a straightforward conclusion is that the elliptic flow for those particles arises from multiple collisions with the more abundant light quarks (already flowing). This suggests that the elliptic flow of particles containing charm quarks may serve as a unique probe of the extent to which frequent re-scatterings of light quarks occurred in the collision and the extent to which the matter produced in central relativistic heavy ion collisions is thermalized. Establishing thermalization of the matter produced at RHIC is a central goal of the RHIC experimental program in heavy ion physics. This measurement can only be accomplished with a detector which is very close to the primary interaction vertex and which is ultra thin to reduce multiple Coloumb scattering to an absolute minimum.

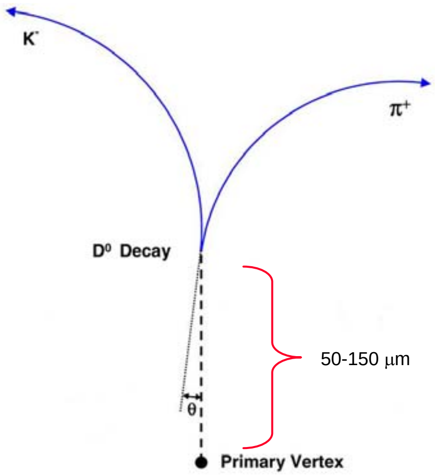

Figure 1. Topology of a neutral D meson decay.

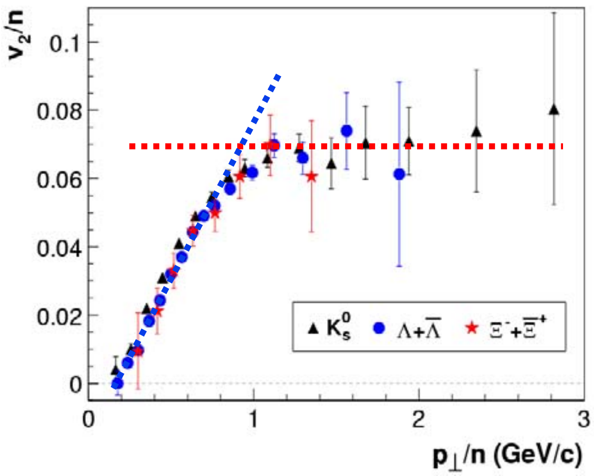

Figure 2: The elliptic flow for various strange meson and baryon species scaled by the number of constituent quarks they contain. The data indicated that strange quarks flow. The proposed HFT will determine if this is also true for charm quarks which are significantly heavier.

Detector Concept:

The proposed HFT detector will reside inside the inner field cage of the STAR TPC and will surround the interaction vertex. It will exploit all of STAR's unique features including full azimuthal coverage at mid-rapidity and the ability to track essentially all charged particles within its acceptance having momenta ≥ ~150 MeV/c. The proposed configuration consists of two tracking layers comprised of monolithic CMOS pixel arrays using 30 μm × 30 μm square pixels. The MAPS layers lie at radii of 2.5 cm and 7.0 cm, respectively. They are active over 20 cm in Z and ultimately provide ~ 135 million pixels of information for every frame taken. This affords tracking information for short lived particle decays displaced by ~ 100 microns (perhaps less) from the primary vertex. In this respect, the proposed STAR HFT is unique. No other silicon detector at RHIC combines extreme pointing accuracy with high efficiency, effectively measuring all particles down to 150 MeV/c; it is these features that enable the HFT to do direct topological reconstruction of open charm hadrons. To achieve this, the silicon chips for the detector must be thinned to 50 μm and mounted on low mass carbon fiber structures to minimize pointing errors generated by multiple Coulomb scattering.

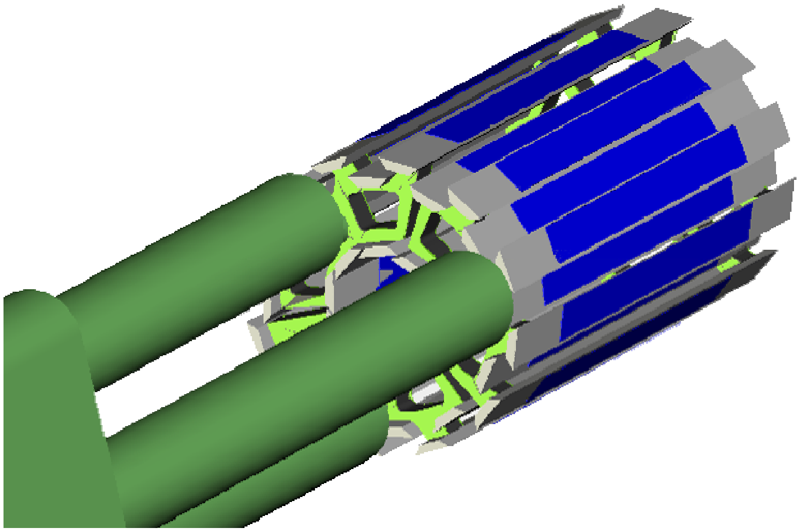

Figure 3: An oblique view of the STAR Heavy Flavor Tracker. The detector has two layers of detector-ladders at 2.5 and 7.0 cm, with 9 and 24 ladders on the inner and outer layers, respectively. There are a total of 135,168,000 pixels on the detector.

Since the Detector Advisory Committee review of the HFT in March 2006, several significant design changes have occurred. A very important one was that the Collider Accelerator Department (CAD) at BNL indicated the size of the beam pipe inside the HFT should be increased. Originally, a beam pipe that was 3.0 cm in diameter was proposed. This diameter beam pipe would have been sufficient for transporting the colliding beams through STAR. However, the small diameter of the proposed beam pipe would have made this the limiting aperture in the RHIC ring which would be highly undesirable in case of an uncontrolled beam dump.

As a result of CAD's request for a design change, both HFT layers were moved outwards. The inner layer of the HFT moved to a radius of 2.5 cm radius and the outer HFT layer moved to a radius of 7.0 cm. The distance between the two layers remained the same as before.

The impact of this change can be estimated using a pocket-formula. The single track pointing resolution for a two layer detector telescope is given in the following formula:

$$\sigma^2 = \frac{\sigma_1^2\, r_2^2 + \sigma_2^2\, r_1^2}{\left(r_2 - r_1\right)^2} + \frac{\theta_{mcs}^2\, r_1^2}{\sin^2(\theta)} \tag{1}$$

where r_1 and r_2 are the radii of the HFT layers, σ_1 and σ_2 are the resolutions of the pixels, θ is the tilt angle of the track, and θ_{mcs} is the width of the multiple coulomb scattering angular distribution in the first layer of the tracker (corresponding to r_1).

θ_{mcs} is momentum dependent and is given approximately by:

$$(2) \qquad \theta_{mcs} = \frac{13.6\,(MeV/c)}{\beta\ p}\sqrt{\frac{x}{X_0}}$$

where the thickness of the detector is measured in radiation lengths, *p* is the particles momentum, and $\beta = p/E$. So for example, the multiple scattering width at 750 MeV for a kaon passing through a 0.28% thick Si detector is ~1.2 milli-radian. This is a useful number because it represents the MCS for kaons carrying half the energy from $D^0 \rightarrow K + \pi$ decays. It is precisely these kaons that must be tracked with high precision.

The result of moving the HFT layers from (1.5 and 5.0 cm) to (2.5 and 7.0 cm) is that the single-track pointing resolution at the vertex increases from 22 microns to 35 microns. This change is significant but relatively small compared to the decay length of the D^0 meson (~125 μm). Thus the decreased vertex resolution decreases the efficiency for finding D^0s modestly. However, there is a compensating efficiency factor. The outer layer of the HFT combined with the IST + SSD + TPC tracking detectors is designed to reliably locate hits on the inner layer of the HFT and associate them with tracks. This is a priori a challenging job because the density of tracks on the HFT is very high in a heavy ion collision. However, by moving the inner HFT layer to a larger radius, the number of hits per square centimeter on this layer is reduced—without decreasing the pointing resolution of the IST+SSD+ TPC+(outer)HFT suite of detectors pointing at it. Thus the track finding efficiency of the HFT goes up even though the pointing resolution at the vertex goes down. This effect partially compensates for the degraded pointing resolution. Further simulation with a full Monte Carlo simulation of the detector in its new geometry will precisely determine the impact of this effect.

Figure 4 shows the efficiency for reconstructing the decay of a D meson ($D^0 \rightarrow K + \pi$) when the pixel information from the HFT and pointing information from the IST discussed in the next section are combined. Note that the mean transverse momentum for the D meson is approximately 1.8 GeV/c and so the efficiency in this region of the plot is of primary interest. The conclusion is that the efficiency for reconstructing D^0 is very good and nearly unchanged from initial projections despite the fact that several design changes have been made and more realistic simulations have been performed since the last review by the BNL Detector Advisory Committee. This result shows that the proposed HFT achieves the necessary performance to afford unique measurements at RHIC in the heavy flavor sector with unprecedented accuracy.

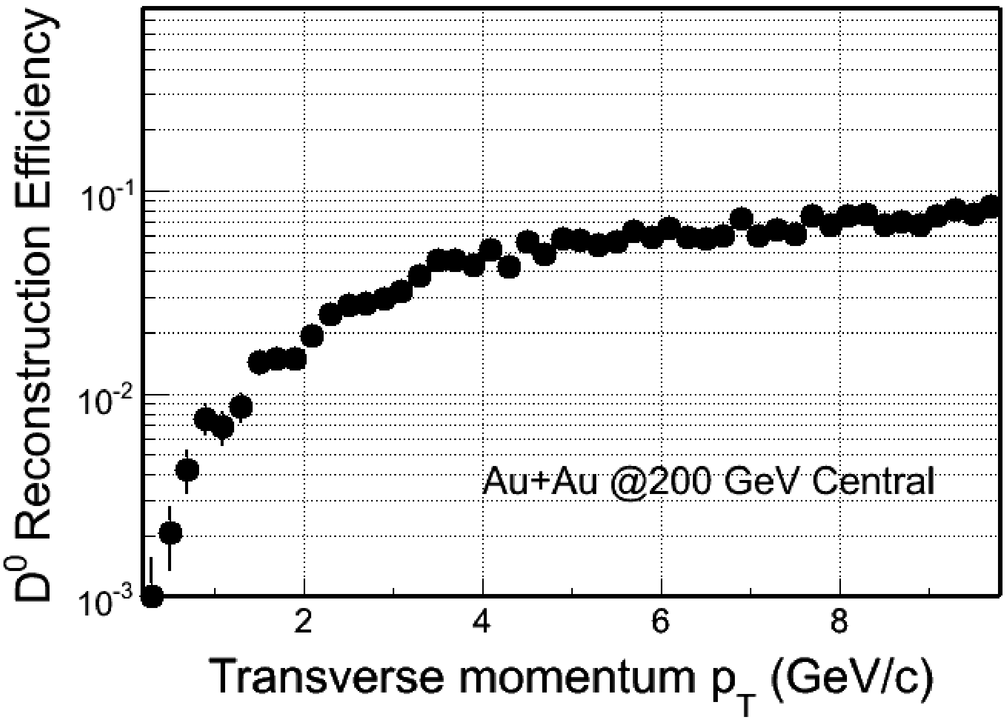

Figure 4: The efficiency for reconstructing a D^0 meson in the STAR HFT as a function of the transverse momentum of the D. The $<p_T>$ for the D is approximately 1.8 GeV/c.

The Intermediate Silicon Tracker (IST) for STAR

The main purpose of the IST is to extend charged particle trajectories found in the existing STAR Time Projection Chamber (TPC) and point them accurately at the outer layer of the HFT at 7 cm radius from the beam-line. The TPC drift volume spans radii of 50-200 cm. It thus provides long track segments to seed the search for particle trajectories and sets precise angular constraints on the track direction. However, the TPC does not provide tight translational constraints on the track position; this is among the main tasks for the proposed intermediate silicon tracker (IST).

In addition to the TPC, a Silicon Strip Detector (SSD) at a radius of 23 cm radius already exists in STAR. It consists of 20 ladders of 67 cm length with double-sided wafers having 95 µm × 4.2 cm strips crossed at an angle of 35 mrad. The strips are oriented so as to improve the r-phi resolution. For tracks at mid-rapidity, the SSD detector material traversed amounts to ~1% radiation lengths. Although the SSD is not discussed further in this writeup, it’s projected performance has been included and used in the simulations described below.

Extensive simulations of the proposed HFT have shown that pointing with the SSD+TPC detectors alone is not a viable solution for the full spectrum of physics measurements planned in STAR, even though it is possible using a vertex constraint determined from the primary collision vertex in Au+Au collisions to make measurements of charm particle production out to 60% peripherality. In order to fully achieve the physics goals of STAR in p+p, p+A, and A+A collisions, two additional high rate conventional silicon barrel layers are proposed at intermediate radii of 12 cm and 17 cm. These strip layers provide space-points with high accuracy in r-phi and in z between the HFT and the existing SSD, reducing the effective search radius at the location of the HFT layers and eliminating spurious HFT hits originating from collision events in prior/later beam crossings. This is particularly crucial to enable accurate measurements in low multiplicity environments.

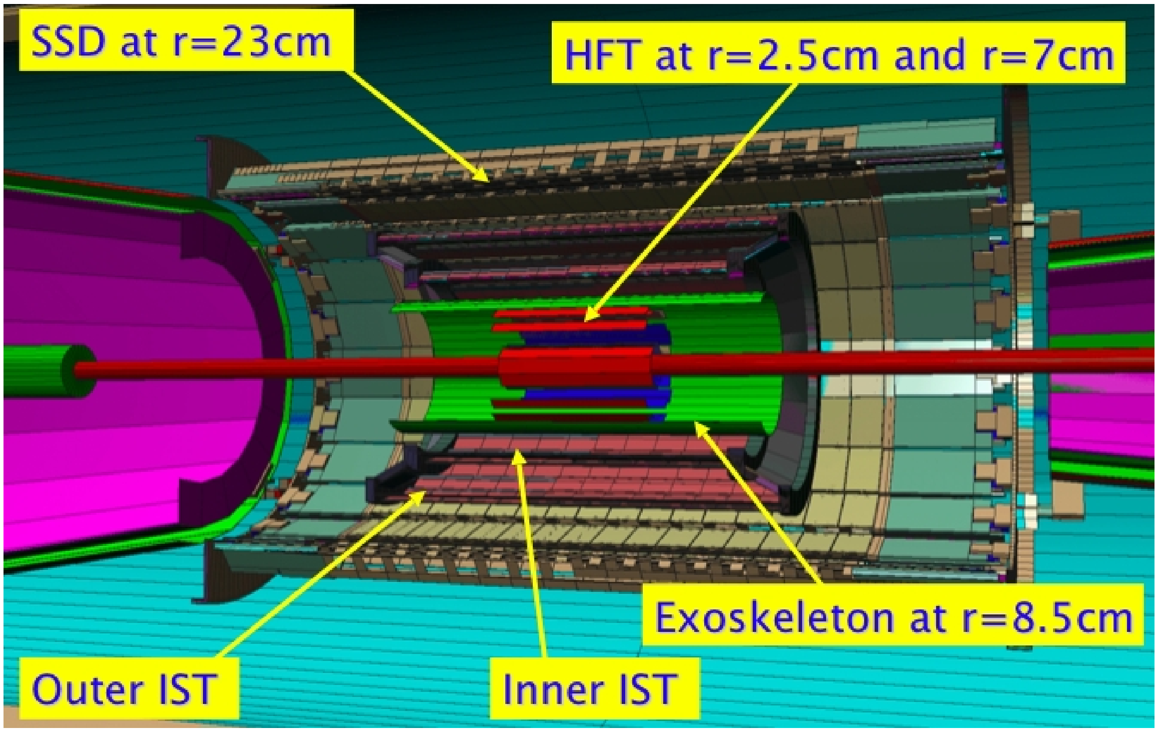

Figure 5: The proposed geometry for the STAR mid-rapidity tracking upgrade. Seen are, from inner to outer radius, the 2 cm beam pipe (red), the two HFT layers (red), the exoskeleton to strengthen the beam pipe (green), the two IST layers (pink), and the existing SSD (black).

IST Detector Concept and Technology

The proposed IST consists of two concentric layers between the HFT and the SSD+TPC, as shown schematically in Fig. 5. Each of the IST layers will be assembled from ladders. The proposed inner layer, at a radius of 12 cm, consists of 19 ladders of 40 cm length. The proposed outer layer, at a radius of 17 cm, consists of 27 ladders of 52 cm length. The ladders are envisioned to carry commercially available 300 μm thick, 4 cm long, single-sided silicon strip sensors and silicon pad sensors mounted "back-to-back" on either side of a support with high thermal conductivity carbon foam (developed at Oak Ridge National Laboratory) as a core and 100 μm kapton hybrids. The design of this support and the overall mechanical structure are the subject of ongoing of R&D. The strip geometry that has been simulated involves 60 μm × 4.0 cm strips, with the strips at outer radius oriented to improve the z resolution and the strips at the inner radius oriented to improve the r-phi resolution. The silicon pad geometry was chosen to be 1.2 mm × 1.9 mm, resulting in an equal number of pad and strip read-out channels. Variations of this layout are being studied and may result in performance improvement with equal channel count or in cost reduction. A total of 692,000 channels are read out with 5.4 k APV25-S1 front-end chips, the same chip developed for use in CMS at CERN. Their 40 MHz output samples are stored in a 4 μs deep analogue pipeline, whose output is processed, multiplexed and sent to digitizer boards. The system will be kept near room temperature and will be air-cooled. A prototype read-out chain has been developed and is being tested. A prototype IST module is under construction.

The geometric acceptance of the IST, $|\eta|<1.2$ and 2π in ϕ, is matched to that of the HFT and TPC. The particle density in a central Au+Au collision at $\sqrt{s_{NN}}$ = 200 GeV amounts to a simulated hit density of 0.4 cm^{-2} at the 17 cm radius of the outer IST layer, corresponding to 0.9% occupancy in a 4 × 4 cm^2 sensor with 640 read-out channels. At the 12 cm radius of the inner IST layer a higher occupancy of 1.9 % is expected. Both particle density and occupancy increase at smaller radii, resulting in ghost hit probabilities in excess of ~10%. Although some of the hit ambiguities in this circumstance can be resolved in principle with sufficiently accurate external tracking information, the tracking ambiguities at radii smaller than 12 cm are too large and a tracking solution using the proposed strip-pad geometry at these small radii is not possible. The proposed IST is sufficiently fast to resolve collisions that originate from crossings of different RHIC beam bunches. This is of particular importance for (polarized) p+p operation, since the number of beam collision events within the HFT frame readout-time is higher than for Au+Au beam operation. Fast simulations show that pointing with the IST is accurate enough to handle the ~0.6 k collision events expected to occur within the 200 μs frame readout-time of the HFT at future RHIC-II p+p luminosities of $L = 1 \times 10^{32}$ cm^{-2} s^{-1}.

For the proposed IST, the detector material traversed at mid-rapidity amounts to ~1.5% radiation lengths for each IST layer, corresponding to a total material budget of ~3% for the entire detector.

Expected Performance

Performance measures were calculated analytically and simulated in the STAR simulation and reconstruction framework. The STAR simulations are GEANT-based. Realistic models for the IST ladders and cables were used.

Pointing resolution at the HFT outer detection layer

Figure 6 shows the expected pointing resolution at the 7 cm radius of the outer HFT layer in the r-phi and z coordinates versus the track transverse momentum. The pointing resolution at the outer HFT layer amounts to ~170 μm in the r-phi coordinate and ~430 μm in the z coordinate for the typical momenta of 0.7 GeV/c of the D^0 decay daughters. This corresponds to a search area of 0.23 mm^2. The HFT has a frame read-time of 200 μs, during which time ~18 Au+Au collision events occur at the projected future RHIC-II peak luminosity of $L = 90\times10^{26}$ cm^{-2} s^{-1}. The hit density, including event overlaps, is estimated to be ~10 cm^{-2} at the 7 cm radius of the outer HFT layer.

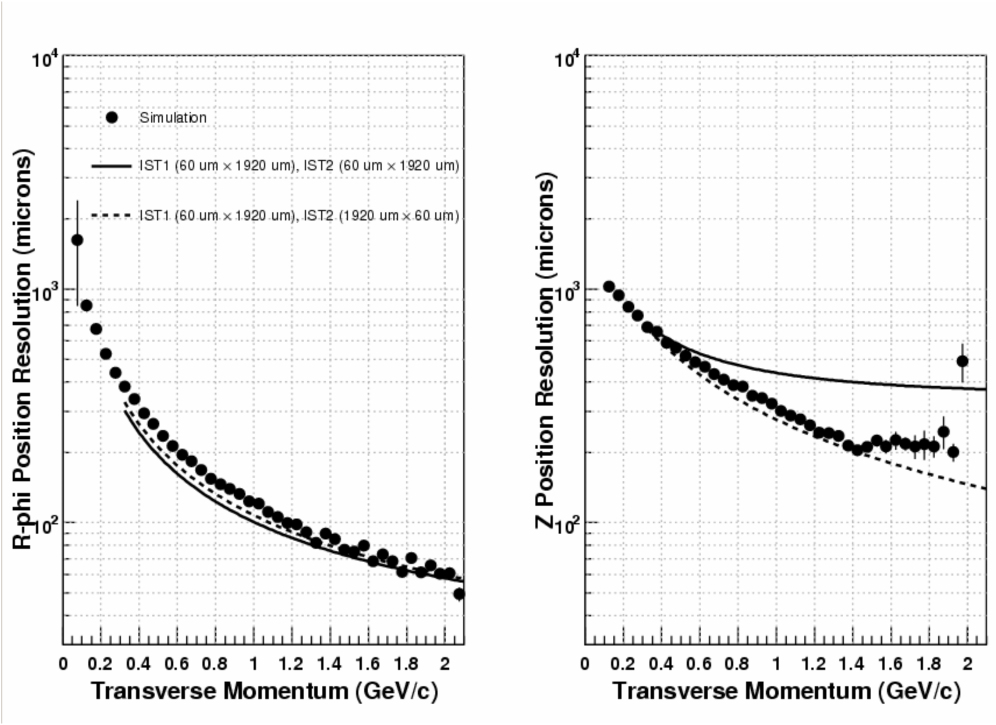

Figure 6: Pointing resolution of the combined TPC, SSD, and IST tracker in the (left) r-phi and (right) z coordinates at the 7 cm outer radius of the HFT versus the track transverse momentum. The points show the results from STAR simulations, and the dashed curve shows the results from analytical calculation. The continuous curve illustrates one of several alternative IST configurations that was considered with the strips in the outer IST layer oriented to improve r-phi resolution. The z resolution is considerably worse in this case than for the proposed configuration.

Direct topological reconstruction of open charm hadrons

The direct topological reconstruction of open charm hadrons is a primary requirement for the proposed tracking upgrades. Figure 4 shows the expected efficiency of finding the $D^0 \rightarrow K^- + \pi^+$ channel in the high multiplicity environment of central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV versus the D^0 transverse momentum using the full tracking suite of HFT, IST, SSD, and TPC in STAR.

The efficiency ranges from ~0.7% at a transverse momentum of 1 GeV/c to ~7% at large transverse momenta, demonstrating the feasibility of measurements over a wide kinematic range.

IST summary

The proposed baseline design for an Intermediate Silicon Tracker in STAR has evolved since the last Detector Advisory Committee review to a two-layer design, with radii of 12 cm and 17 cm. It continues to make use of conventional silicon strip technology. Simulations show that the current baseline IST design, using a "back-to-back" configuration of single-sided strip (pitch 60 μm) and pad sensors (wafer size 4 cm × 4 cm), sufficiently improves STAR's pointing capability to the HFT, making open charm hadron measurements viable over a wide kinematic range.

The STAR Forward GEM Tracker (FGT)

A future core goal of the STAR scientific spin program is to carry out measurements to determine the flavor-dependence (Δu-bar versus Δd-bar) of the sea quark polarization, and thereby examine the mechanism for producing the sea in a proton. Those polarized distribution functions are only weakly constrained by polarized fixed-target DIS experiments [1]. This will be probed using parity-violating W production and decay. The method for extracting spin-dependent quark distributions based on the reconstruction of the single-longitudinal spin asymmetry as a function of the W rapidity is not possible since reconstruction of the W is only possible with a hermetic detector. However it has been shown that most of the sensitivity to anti-quark polarizations is preserved in the leptonic observables. The theoretical framework on the measurement of the single-longitudinal spin asymmetry as a function of the leptonic rapidity has been presented in [2]. Reliable predictions are provided based on re-summation calculations. These calculations have been incorporated in a Monte-Carlo program called RHICBOS. These concepts have been used extensively for the W mass measurement at the Tevatron. The sensitivity for STAR has been estimated using the RHICBOS MC program [2] .

The sensitivity to different distribution functions of the underlying quark and anti-quark distributions based on GRSV-STD, GRSV-VAL [3] and GS-A [4] is shown in Figure 7. GRSV-VAL considers a flavor asymmetry scenario of Δu and Δd whereas GRSV-STD is based on a flavor symmetry description. The projections in Figure 7 are shown for a beam polarization of 70% and an integrated luminosity of 400 pb^{-1}. Clear discrimination power as to the choice of the underlying distribution function is seen in the forward direction in case of W^- production. For W^+ production, the sensitivity is similar in the forward and barrel region.

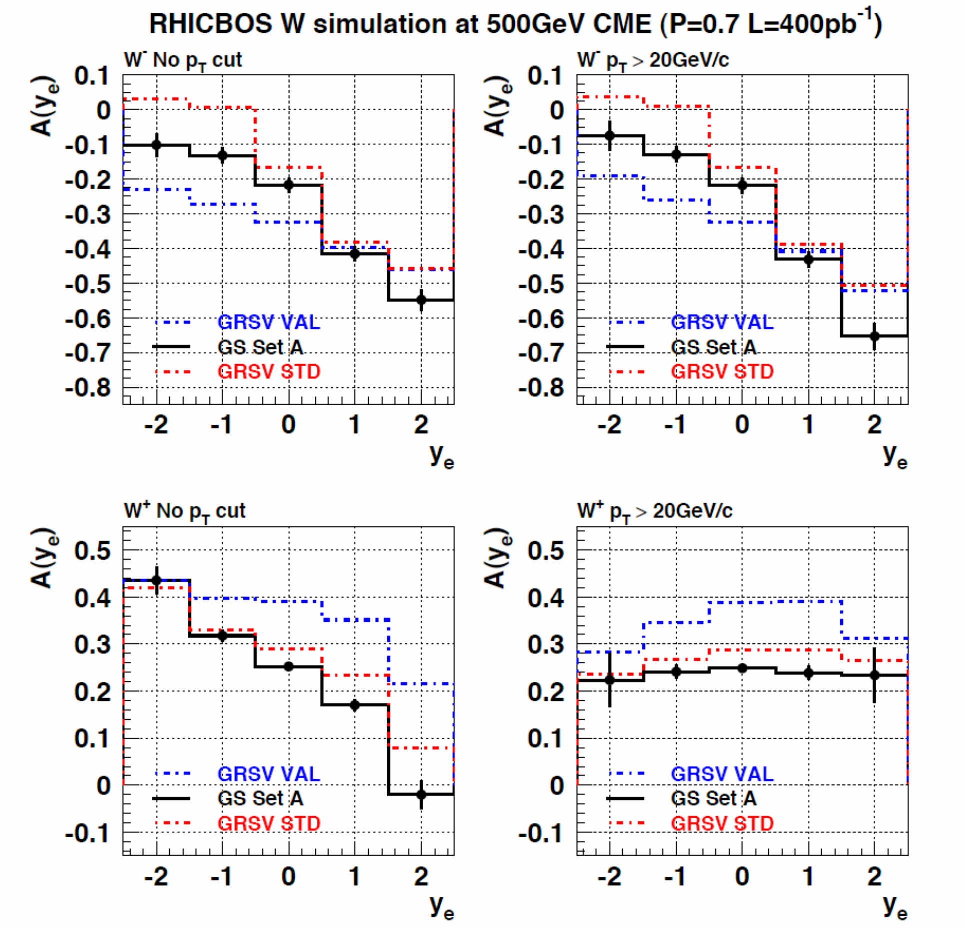

Figure 7: The sensitivity to different underlying quark and anti-quark distributions based on GRSV-STD, GRSV-VAL [3] and GS-A [4]. GRSV-VAL considers a flavor asymmetry scenario of Δu and Δd whereas GRSV-STD is based on a flavor symmetry description.

The production of $W^{\pm}$ bosons provides an ideal tool to study the spin-flavor structure of the proton. $W^{\pm}$ bosons are produced in u-bar+d (d+u-bar) collisions and can be detected through their leptonic decays into an electron and a neutrino, or the corresponding anti-particles. Forward scattered $e^{\pm}$ tagged in the STAR Endcap ElectroMagnetic calorimeter (EEMC) ($1 < \eta < 2$) off the incoming polarized proton beam moving toward (away) from the STAR EEMC, yield a purity for $W^{\pm}$ coming from u-bar+d (d+u-bar) quarks of about 98% (75%) [5]. The separation of $e^{\pm}$ from hadronic background will be important and therefore the full exploitation of the STAR EEMC with its intrinsic means for e/h separation (pre-shower and post-shower readout system) will be crucial. The discrimination of u-bar+d (d+u-bar) quark combinations requires distinguishing between high p_T $e^{\pm}$ through their opposite charge sign which in turn requires precise tracking information. The resolution of the STAR Time-Projection Chamber (TPC) and its capability for charge sign discrimination deteriorates rapidly beyond $|\eta| > 1$ as shown in Figure 8. This is especially true for high p_T tracks. An upgrade of the STAR forward tracking system is therefore needed to provide the required tracking precision for charge sign discrimination. The forward tracking system would consist of six triple-GEM detectors with two dimensional readout arranged in disks along the beam axis, referred to as the Forward GEM Tracker (FGT).

Figure 8 shows the charge sign discrimination probability determined as the ratio of the number of reconstructed tracks requiring the correct charge sign divided by the number of generated tracks. All results shown are based on the full STAR GEANT simulation framework for single electrons of p_T=30GeV/c. In all cases a beam line constraint is taken into account. Two configurations are shown for TPC only (left) and TPC+EEMC shower maximum detector (SMD) (right). The EEMC-SMD provides a hit resolution at the level of 1.5mm. The EEMC-SMD provides some level of improvement towards larger rapidity in the EEMC acceptance region ($1<\eta<2$). However, a clear drop for $\eta \sim 1.5$ is observed. The case for Z=-30cm is somewhat better than Z=0cm and in particular compared to Z=+30cm. This is because of the larger number of TPC padrows that are available for track reconstruction. Figure 9 shows the charge sign discrimination probability for TPC, the inner tracking system consisting of IST+SSD and the proposed configuration of 6 FGT triple-GEM disks. A magenta vertical line marks the limits of the EEMC coverage in η. A magenta horizontal line marks the 80% level of the charge sign discrimination probability. Good charge sign discrimination probability is obtained for the proposed configuration of 6 FGT disks.

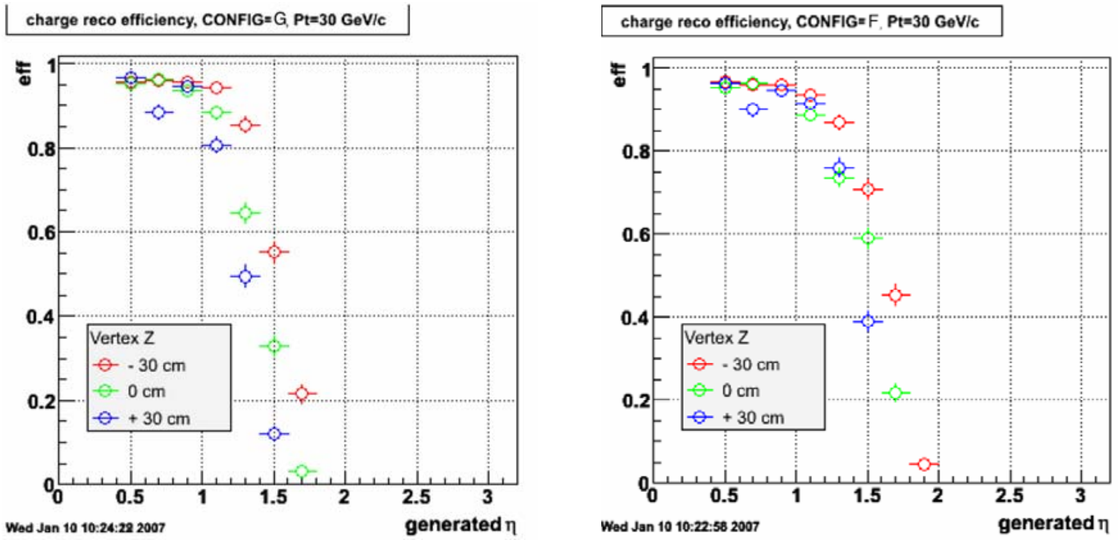

Figure 8:. Charge sign discrimination probability determined as the ratio of the number of reconstructed tracks requiring the correct charge sign divided by the number of generated tracks as a function of η for the case of the TPC only (left) and TPC+EEMC+SMD (right).

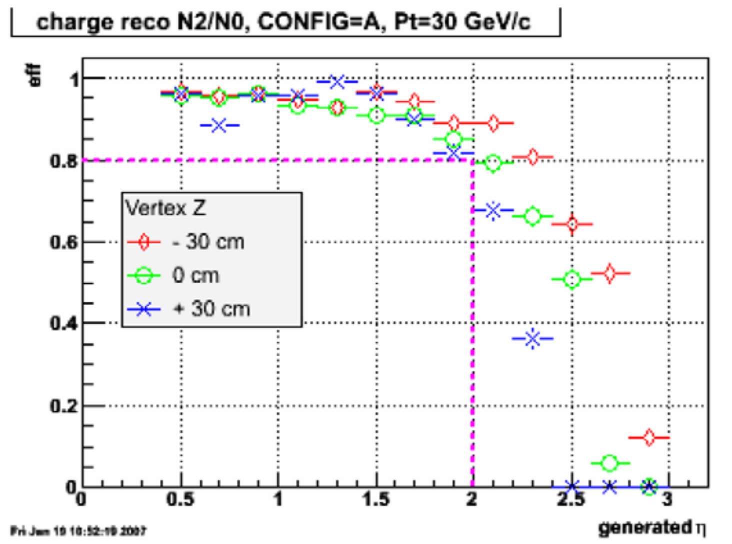

Figure 9: Charge sign discrimination probability determined as the ratio of the number of reconstructed tracks requiring the correct charge sign divided by the number of generated tracks as a function of η for the case of 6 FGT disks including the inner tracking system of SSD+IST.

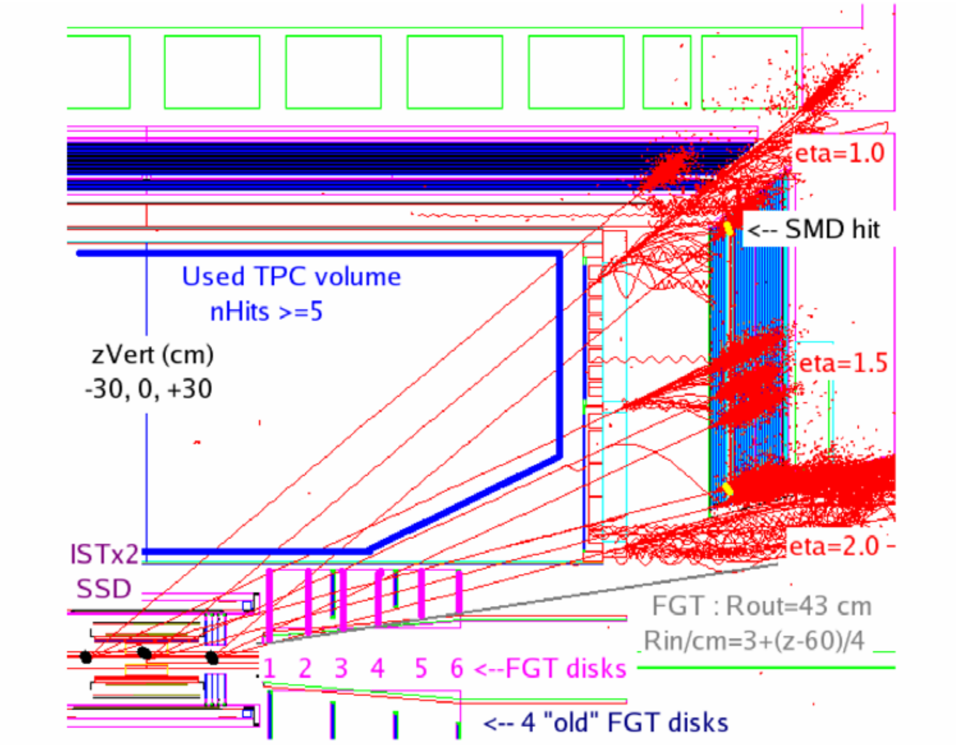

Figure 10: Layout of the Forward GEM Tracker, consisting of six triple-GEM detector disks. Tracks of electrons with 40 GeV E_T are overlaid from three Z vertex locations at -30 cm, 0 cm and +30 cm with three different η values of 1.0, 1.5 and 2.0 for each vertex location. Also visible is the multi-layer barrel inner tracking system based on the HFT, IST and SSD. The previous FGT configuration is shown at the bottom. The former FST disks are not used in the current layout.

The forward tracking components provide precision tracking in the range of $1 < \eta < 2$, giving charge sign discrimination for leptonic decays of W bosons. The charge sign determination of forward scattered $e^{\pm}$, tagged in the STAR EEMC in polarized proton-proton collisions is the main motivation for the STAR forward tracking upgrade.

The forward tracking detectors cover $+1 < \eta < +2$. The six triple-GEM type disks of the Forward GEM Tracker (FGT) can be seen in Figure 10. Tracks of electrons with E_T of 40 GeV are overlaid for three different η values (1.0, 1.5, 2.0), originating from three Z vertex locations at -30 cm, 0 cm and +30 cm. Also visible is the multi-layer barrel inner tracking system based on the HFT, IST and SSD. In addition a previous FST+FGT configuration is shown. It consisted of four FGT disks and four silicon disks (FST) at smaller radii closer to the interaction region.

Several options have been studied based on disk and barrel arrangements. The proposed configuration, based on six triple-GEM disk detectors, addresses several issues such as optimized acceptance taking into account the Z vertex distribution with a Gaussian sigma of about 30 cm. It has been shown that a disk configuration is optimal in terms of acceptance in comparison to a barrel configuration in particular at large η. The proposed configuration provides a rather cost effective solution based only on GEM technology. The usage of additional silicon disks (FST) at smaller radii as originally anticipated does not yield an improvement in performance and is no longer considered.

GEM technology is widely employed by current and future experiments in nuclear and particle physics. A SBIR proposal (Phase 1 and Phase 2) has been approved and is the basis for the industrial production of GEM foils to be used for the forward GEM tracking system. The readout system for both the intermediate (IST) and forward (FGT) tracking systems are based on the APV25-S1 readout chip which has been extensively tested for the CMS silicon tracker and is also used by the COMPASS triple-GEM tracking stations. A common chip readout system will significantly simplify the design of the overall readout system for the integrated tracking upgrade. The proposed configuration is based on light-weight materials to limit the amount of dead material in the forward direction. It provides also the possibility to decouple the inner and forward tracking system from a mechanical perspective. In summary, the charge-sign discrimination of high-p_T $e^{\pm}$ to distinguish $W^{\pm}$ bosons is based on using a beam line constraint, precise hit information from six triple-GEM disks, hits at forward η from the TPC and the electromagnetic-cluster hit information from the shower-maximum detector of the STAR EEMC.

It should be stressed that the integrated tracking upgrade for STAR, based on well established, intrinsically fast detector and readout elements, will provide a significant improvement of the existing STAR tracking system, in particular for the expected high luminosity operation at RHIC.

Summary

A comprehensive upgrade of STAR tracking capability at mid and forward rapidity is proposed. This upgrade is essential to provide new capability for the measurement of particles containing heavy quarks in (polarized) p+p, p+A, and AA collisions resulting in significant extension of the scientific reach of STAR. Important physics questions to be addressed include the nature of the process by which partons lose energy in the dense hadronic matter produced in central heavy ion collisions, and the extent to which that matter is thermalized; as well, the spin structure of the nucleon. The proposed detectors comprise a next generation micro-vertex detector at mid-rapidity using a combination of monolithic active pixel sensors (MAPS) and conventional silicon strip technology and a new forward tracking detector based on cutting edge Gas Electron Multiplication (GEM) technology. The scope of the construction for the mid-rapidity and forward tracking upgrades is fully consistent with the projections made in the BNL Mid-Term Plan. The proposed construction projects are highly leveraged by significant contributed labor. These contributions will be provided by participating institutions from the STAR Collaboration, which is fully committed to the timely completion of these upgrades as a central and essential piece of the Collaboration's vision for its scientific future at RHIC.

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