R&D proposal

STAR Inner and Forward Tracking Upgrade

STAR Tracking Upgrade Working Group

February 17, 2006

1 Introduction

The STAR collaboration is preparing a challenging detector upgrade program to further investigate fundamental properties of the new state of strongly interacting matter produced in relativistic-heavy ion collisions at RHIC and to provide fundamental studies of the nucleon spin structure and dynamics in high-energy polarized proton-proton collisions at RHIC.

A key step in this direction is the ability for the direct reconstruction of charm and beauty decays as well as flavor tagged jets to allow a precise measurement of the spectra, yields and flow of open charm and beauty production. The measurement of the nuclear modification factor R_{AA} from central to peripheral collisions is a critical step for particles containing heavy quarks. This will allow fundamental tests of QCD predictions of heavy quark energy loss.

The second core goal of the STAR scientific program is to carry out spin physics measurements to study the spin structure of the proton. The contribution to the proton spin from gluons will be determined as a function of the momentum fraction using direct photon + jet, charm and beauty production, inclusive jets and di-jet production. The flavor-dependence ($\Delta\bar{u}$ versus $\Delta\bar{d}$) of the sea quark polarization, and thereby the mechanism for producing the sea in a proton, will be probed using parity-violating W production and decay.

The reconstruction of open charm and beauty production requires a precision micro-vertex detector and inner tracking detector capable of directly observing charm and beauty decays. This is the focus of the Heavy Flavor Tracker (HFT), a high-resolution micro-vertex detector based on active pixel sensor (APS) technology. A CD0 proposal is currently under preparation. The reconstruction of open charm and beauty production in proton-proton collisions and for low multiplicity events in relativistic heavy-ion collisions requires a new intermediate tracking system together with the existing STAR silicon-strip detector (SSD) and the STAR Time-Projection Chamber (TPC). This new silicon barrel detector, the Inner-Silicon Tracker (IST), is expected to replace the current STAR Silicon Vertex Tracker (SVT) which is based on silicon drift detectors. The IST would establish a track-pointing device for the HFT, connecting TPC tracks to the high-precision inner HFT layers. The anticipated design of the IST will be compatible with the STAR DAQ-upgrade (DAQ1000). A combination of well-established silicon strip sensors and silicon pad sensors is foreseen for the IST design. The R&D requirements will be discussed in section 3-5.

An upgrade of the STAR inner tracking system, would allow an extension of the capabilities to measure the gluon contribution to the proton spin through heavy quark (charm/bottom) production. Figure 1 shows the result of a calculation of the partonic double-longitudinal spin asymmetry for $gg \rightarrow Q\bar{Q}$ as a function of $\sqrt{\hat{s}}/2M$. The range covered by the RHIC kinematics in case of $M = m_c$ (charm mass) for $\sqrt{s} = 200 - 500\,\mathrm{GeV}$ is shown together with the low energy and massless quark limit [8]. Experimental confirmation of the predicted dependence would provide a stringent test of the underlying Standard Model dynamics. Generally, the extension of the gluon polarization program including heavy flavor production would provide an extension of the kinematic coverage in particular towards lower values of Bjorken-x. Including various different underlying process in the extraction of the polarized gluon distribution function through a global analysis will be crucial. The NLO formalism has been worked out and is available in [9].

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 obstructed by specifies of the detection of W bosons at RHIC since non of the current RHIC detectors are hermetic. The measurement of the single-longitudinal spin asymmetry as a function of the leptonic rapidity has been presented in [4]. Reliable predictions are provided based on resummation 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. Figure 2 (left) shows the W kinematic of the partonic Bjorken x_1, x_2 and lepton rapidity y of the RHIC coverage at $\sqrt{s} = 500\,\mathrm{GeV}$ in comparison to the Tevatron ($\sqrt{s} = 1.96\,\mathrm{TeV}$) and LHC ($\sqrt{s} = 14\,\mathrm{TeV}$). This shows that RHIC has a clear window to high-x parton distribution functions in the region of $|y| < 2$. The Tevatron and in particular the LHC program require very forward coverage to access the same high-x kinematics region through W production. Figure 2 (right) shows the result of RHICBOS [6] simulations of leptonic single-longitudinal spin asymmetry as a function of the lepton radidity comparing three different sets of polarized distribution functions. The sets of GRSV-STD and GRSV-VAL [7] differ by the assumption of a completly flavor symmetric and asymmetric case. Overall, the largest sensitivity is reached at forward rapidity.

The production of $W^{-(+)}$ bosons provides an ideal tool to study the spin-flavor structure of the proton. $W^{-(+)}$ bosons are produced in $\bar{u}+d(d+\bar{u})$ collisions and can be detected through their leptonic decays, e.g. electrons. Forward scattered $e^{-(+)}$ 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 $W^{-(+)}$ coming from $\bar{u} + d(d + \bar{u})$ quarks of about 98% (75%). The separation of $e^{-(+)}$ 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 $\bar{u}+d(d+\bar{u})$ quark combinations requires distinguishing between high p_T $e^{-(+)}$ through their opposite charge sign which in turn requires precise tracking information. The resolution of the STAR Time-Projection Chamber (TPC) deteriorates rapidly beyond $|\eta| > 1$. It does not permit charge discrimination for high p_T tracks. An upgrade of the STAR forward tracking system is needed to provide the required tracking precision for charge sign discrimination. The forward tracking system would consist of 4 silicon strip disks, the Forward-Silicon Tracker (FST) and a larger area GEM layer, the Forward-GEM Tracker (FGT). 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 $e^{-(+)}$, tagged in the STAR EEMC in polarized proton-proton collisions is the main motivation for the STAR Forward Tracking Upgrade. A CD0 level proposal for the STAR Inner and Forward Tracking Upgrade is currently in preparation. Section 3-5 will provide an overview of the foreseen R&D activities.

2 Progress report

Silicon as well as GEM-type tracking detectors are being considered in the design of the new STAR tracking system among the following collaborationg institutes: ANL, BNL, IUCF, LBL, MIT, Yale University, Zagreb University. This effort is making use of the existing infrastructure, in particular at MIT, such as the LNS silicon laboratory and a new GEM detector laboratory.

Various simulation tools (GEANT and device simulation) and tracking software have been developed. A side view of the GEANT simulation is shown in the center of Figure 3. The engineering design of a triple-GEM based tracking system (Forward-GEM Tracker: FGT) in front of the STAR Endcap ElectroMagnetic Calorimeter (EEMC) is shown on the right side of Figure 3. The engineering layout of a new inner-barrel (Inner-Silicon Tracker: IST) and forward-disk (Forward-Silicon Tracker: FST) silicon tracking system is shown on the left side of Figure 3. The inner-two barrel layers based on an Active-Pixel Sensor Detector (Heavy-Flavor Tracker: HFT) are also shown.

The engineering effort centered at MIT Bates is currently focusing on the design of a support structure for the inner (IST) and forward (FST) tracking system. An integrated design approach is critical. Carbon fiber support structures are being considered. Those are rountinely being used at various high-energy silicon based tracking devices.

R&E work on the design and manufacturing of silicon prototype modules is carried within the MIT LNS silicon laboratory.

An initiative to design, assemble and test triple-GEM tracking detectors has been completed. A chip readout system based on the APV25-S1 chips has been finished and is currently being tested. This effort follows closely the expertise gained by the COMPASS collaboration at CERN, which successfully operates 20 large-size triple-GEM detectors in a high-rate environment [12].

A GEM laboratory has been set up at MIT and Yale based on an existing Class 1000 clean room. The clean-room equipment at MIT includes basic equipment such as specialized chairs, shelves and work benches besides a Hepa-Filter system. The setup of a basic DAQ system for the readout of triple-GEM chambers, a CCD-camera based GEM-foil scanning device and a vacuum chamber for initial tests of GEM foils and triple-GEM chambers has been completed.

Several prototype triple-GEM chambers have been manufactured and are now in the process of being assembled and tested. This work is carried out in the newly established GEM laboratory at MIT. Several activities are ongoing to complete the assembly of several prototype triple-GEM chamber. The design of those chambers will be discussed in detail below. This includes a setup to initially stretch GEM foil prior to their final gluing onto carrier frames. Those frames are then installed inside a triple-GEM chamber.

All ongoing activities in the GEM laboratory involve two undergraduate students from the MIT Undergraduate Research Opportunity Program (UROP).

Figure 4 shows a bottom and top view of the prototype triple-GEM chambers. Those chambers have been designed at MIT-Bates. The location of the sensitive detector volume can be clearly seen on the right side of Figure 4 with the location of three inner G10 carrier frames. No GEM foils have yet been glued onto those frames. The sensitive GEM foil area amounts to $10 \times 10\text{cm}^2$. The bottom of this sensitive volume consists of orthogonal readout strips with a readout pitch of $635\mu m$. The charge induced on each individual strip is read out by a APV25-S1 readout chip which is glued and bounded onto separate readout hybrids. Each readout hybrid reads out 64 readout strips providing a total of 192 readout channels for each orthogonal direction (X/Y). The location of groups of three readout hybrids can be clearly seen on the left photograph in Figure 4.

The orthogonal readout strips is an integral part of the readout plane which includes also a readout bus system for the readout hybrids which are mounted onto the readout plane by minature connectors. This provides enormous flexibility in case of failure of a readout chip to simply replace a readout board instead of rebuilding a complete readout plane.

An exploded view of the triple-GEM chamber design is shown in Figure 5. Each chamber consists of a 2D readout board which is based on a conventional printed circuit board. The 2D readout strip structure is glued on one side onto each 2D readout board. The actual triple-GEM chamber is then built up on top of this strip readout structure. The is the view of the chamber as shown on the right side in Figure 4. The connection of each readout strip to the back side which is shown on the left side in Figure 4 is provided through vias connections. Those are then connected to individual readout hybrids combining 64 readout strips onto one readout hybrid.

The design of a control unit based on state-of-the art FIFO and FPGA circuits has been completed. Those control units provide the link between individual APV25-S1 readout channels and the DAQ system. An effort lead by Argonne National Laboratory and MIT-Bates is underway to integrate this system into the STAR DAQ environment. This is part of the overall plan to install and test a set of at least three triple-GEM chambers inside STAR under beam conditions.

A prerequisite for mass production of triple GEM tracking detectors is the availability of GEM foils. So far, the only source for these devices has been the CERN-EST-DEM photolithographic workshop. However, their capacity is limited and unable to meet the increasing worldwide demand for GEM foils. To address this problem a collaboration with the Plymouth, MA based company TechEtch has been formed and a SBIR proposal has been formulated.

GEM foils are now routinly produced by Tech-Etch, Inc. in Plymouth, MA. The goal of the recently approved SBIR proposal by Tech-Etch Inc. in collaboration with BNL, MIT and Yale is to develop the technology at Tech-Etch for commercial production of GEM foils which meet the requirement of use in nuclear and particle physics and astrophysics research besides long-term medical imaging and homeland security applications. The focus of Phase I of the SBIR proposal is to determine the role of materials, process and post-process handling. The production of various test GEM foil samples is ongoing.

An optical scanner was developed to measure the parameters of the foils and to test them for defects [11]. A triple GEM detector prototype based on 10 cm × 10 cm GEM foils has been developed and was tested with foils made at CERN. The prototype has a two dimensional projective strip readout with 635 μm pitch laser-etched onto a printed circuit board, and a gas-tight body made out of aluminum and G10. The GEM foils are stretched and glued onto frames that guarantee the correct distance between foils. The high voltage to the foils is provided via a resistor network. The detector is operated with a gas mixture of Ar:CO_2 70:30.

A readout system based on NIM and CAMAC electronics connected to a standard PC has been set up to read out groups of channels prior to the final APV25-S1 readout test. The detector was irradiated in different positions with a collimated ^{55}Fe source emitting 5.9 keV X-rays to determine the relative gain variations over the active area. The quality of the X-ray spectrum is used as an indicator of the overall detector quality. Figure 6 shows a spectrum recorded with the CERN foil based triple GEM prototype. The quality of the spectrum and the energy resolution is comparable to that obtained with the COMPASS triple GEM detectors [12].

A collaboration between TechEtch, MIT, Yale and BNL has been established to work on the optimization of the GEM foils produced by TechEtch. Foils produced under a variety of conditions using different materials will be tested at the institutions to determine their properties, thus identifying optimal conditions and materials for the final product.

The following part provides an overview of contributed labor and material by MIT to R&D work carried out so far as part of the STAR tracking upgrade effort:

Estimated contributed technical labor (MIT):

- 1 mechanical engineer (1/4 year)
- 1 electronics engineer (1 year)
- 1 technician (1/4 year)

Estimated contributed material cost (MIT): Total: \$55k

- Clean room: \$20k
- Clean room equipment: \$10k
- Readout electronics: \$5k
- Chip readout system: \$10k
- Triple-GEM prototype mechanics: \$5k
- GEM foils: \$2.5k
- Misc. items: \$2.5k

The contribution by ANL and Yale has been estimated to be 5k and 10k, respectively. Both insitutes provided in addition technical help.

3 R&D activities in 2006

The following R&D activities are foreseen:

- Simulation of IST and FST/FGT
- Finalize design of IST silicon strip and pad sensors
- Order of IST silicon strip and pad sensors
- Mechanical design of support structure (HFT/IST/FST)
- Design of IST hybrid chip readout system

Requested funds: \$200k

- Fabrication of IST prototye sensors: 2 X \$60k
- Order of 2 X 10 (strip and pad sensors): 2 X \$15k
- Order of IST hybrid prototypes: \$30k
- Order of GEM laboratry equipment (X-ray sourse and scanner): \$10k
- Order of GEM laboratory control units (pressure, temperature, oxygen, humidity): \$10k

4 R&D activities in 2007

The following R&D activities are foreseen:

- Finalize design of FST silicon strip sensors
- Order of FST silicon strip sensors
- Mechanical design of support structure (FGT)
- Design of FST/FGT hybrid chip readout system
- Test of IST and FST silicon prototypes
- Design, manufacturing and test of STAR specific FGT prototype chambers
- Design of cables, cooling and alignment system

Requested funds: \$200k

- Fabrication of FST prototye sensors: \$60k
- Order of 10 strip sensors: \$30k
- Order of FST/FGT hybrid prototypes: 2 X \$30k
- FGT prototype chambers: \$50k

5 R&D activities in 2008

The following R&D activities are foreseen:

- Finalize desing of cables, cooling and alignment system
- Test of IST and FST silicon prototypes
- Test of FGT prototypes
- Manufacturing and test of IST/FST/FGT modules

Requested funds: \$500k

- Fabrication of IST modules: \$100k
- Fabrication of FST modules: \$100k
- Fabrication of FGT chambers: \$100k
- Manufacturing of cables: \$100k
- Prototype alignment and cooling system cost: \$100k

6 Preliminary cost estimate

The following three sections will provide a first cost estimate for the inner silicon barrel system, the inner silicon forward disks and the forward GEM tracking detector. It is understood that this is a preliminary cost evaluation which will be replaced by a refined cost analysis for the actual proposal of each proposal stage. Various details on the final layout such as the number of silicon barrel layers, the length and radius of each barrel layers as well as the the inner and outer radii and the distance to the nominal interaction point of the forward disks is subject to on-going simulation work. The last section provides a funding profile starting from fiscal year 2005 until fiscal year 2009 to achieve the completion of an integrated tracker for the STAR experiment at RHIC in a timely fashion.

6.1 Preliminary cost estimate: Inner Silicon Tracker (IST)

The following comments have to be taken into consideration for the cost estimate of the silicon barrel system:

- The exact layout is not finalized. The occupancy and required performance need to be still resolved through on-going simulation work. For the time being, an inner silicon barrel system of three layers covering the pseudo-rapidity region of $-1 < \eta < 1$ is assumed. A conservative design would then consist of silicon strip sensors with each layer consisting of stereo pairs.

- The size of the silicon sensors, quantified by the the strip length, will determine the occupancy. In principle, one would like to push the first layer as close as possible to the pixel layer. If one restricts the design to one (or rather 2 because of the required stereo angle) sensor type then the closest one can get is to a radius of 70 mm, below that the occupancy for central Au+Au collisions will be above 10%.

- It is foreseen to use the APV25-S1 chip which leads to a strip pitch of about $50\,\mu$m. It has been shown that by introducing an additional floating strip between the active strips, sub-$10\,\mu$m resolutions are feasible. If a 90° stereo angle is used, each layer would then allow a space

Item	Design A		Design B		Remarks
	Amount	k$	Amount	k$	
Sensors	894	894	1392	1392	$1000/sensor
Sensor R&D		100		100	$50k times 2 types
Hybrids	260	130	464	232	$500/berillia substrate thin film
Hybrid R&D		50		50	
APV25 chips	4470	120	6960	174	$25/chip
Cables	260	130	464	232	$500/low mass cable
Cable R&D		50		50	
FEE	572160	600	890880	900	$1/channel, in house R&D
Integration FEE/DAQ		100		100	
Power Supply		100		100	Power and bias supplies
Cooling		200		200	Under-pressure water cooling
Mechanics		1000		1000	Low mass, in house R&D
Misc. items		100		100	
Total		3574		4630	No contingency and overhead

Table 1: Cost estimate for the inner silicon barrel system. This estimate is based on a sensor size of 40 cm^2 and one stereo pair per layer. 'Design A' refers to system of 3 layers with radii of 70 mm, 150 mm and 170 mm whereas 'Design B' refers to a system with radii of 100 mm, 150 mm and 200 mm.

point resolution at the level of sub-10 μm precision. This would then result in a double metal sensor design.

- The current estimate relies heavily on the PHOBOS experience gained during the silicon detector design and construction.
- The cost estimate does not include any contingency, overhead and any cost for personnel. The last cost item are expected to be already covered by existing personnel at participating institutes.

Table 1 provides an overview of the various cost items for the inner silicon barrel system. This estimate is based on a sensor size of 40 cm^2 and one stereo pair per layer. 'Design A' refers to system of 3 layers with radii of 70 mm, 150 mm and 170 mm whereas 'Design B' refers to a system as shown in Figure 2 and 1 with radii of 100 mm, 150 mm and 200 mm.

6.2 Preliminary cost estimate: Forward Silicon Tracker (FST)

Item	Disk design		Remarks
	Amount	k$	
Sensors	675	675	$1000/sensor
Sensor R&D		100	$50k times 2 types
Hybrids	196	98	$500/berillia substrate thin film
Hybrid R&D		25	
APV25 chips	3370	85	$25/chip
Cables	260	130	$500/low mass cable
Cable R&D		25	
FEE	431360	450	$1/channel, in house R&D
Integration FEE/DAQ		100	
Power Supply		100	Power and bias supplies
Cooling		100	Under-pressure water cooling
Mechanics		300	Low mass, in house R&D
Misc. items		100	
Total		2288	No contingency and overhead

Table 2: Cost estimate for the inner forward silicon disk system.

The comments made in the previous section on the assumption of the preliminary cost estimate applies as well to the following discussion of the inner forward silicon disk system. The respective cost items are shown in Table 2 based on the conceptual layout shown in Figure 2 and 1. It is assumed that the main part of the mechanical support structure is in place after the 'Stage 1' installation.

6.3 Preliminary cost estimate: Forward GEM Tracker (FGT)

Item	Disk design		Remarks
	Amount	k$	
GEM chamber mechanics	200	100	$500/chamber
GEM foils	900	180	$200/GEM foil
Hybrids	728	364	$500/berillia substrate thin film
Hybrid R&D		25	
APV25 chips	1456	40	$25/chip
Cables	260	130	$500/low mass cable
Cable R&D		25	
FEE	186368	190	$1/channel, in house R&D
Integration FEE/DAQ		100	
Power Supply		100	Power and bias supplies
Cooling		30	Air flow system
Mechanics		300	Low mass, in house R&D
Misc. items		100	
Total		1684	No contingency and overhead

Table 3: Cost estimate for the outer forward GEM detector based on individual triple-GEM chambers.

The cost estimate of the outer forward GEM detector is based on the conceptual layout shown in Figure 3 using individual triple-GEM chambers. Each considered cost item is shown in Table 3.

7 Preliminary funding profile

Based on the cost estimates provided in the last three sections, a funding profile has been developed from fiscal year 2008 until fiscal year 2011 to achieve the completion of an integrated tracker for the STAR experiment at RHIC in a timely fashion. Achieving such a funding profile will be crucial to continue with a competitive physics program of the STAR experiment by the end of this current decade for the relativistic-heavy ion program as well as for the polarized proton-proton program at RHIC at BNL. The 'Design A' option is assumed for the IST.

A preliminary funding profile is shown in Table 4 and 5.

References

[1] G. Bunce *et al.*, Ann. Rev. Nucl. Part. Sci. **50** (2000) 525.

[2] RHIC SPIN document, edited by G. Bunce, February 2005, BNL internal note.

[3] B. Dressler et al., Eur. Phys. J. C18 (2001) 719; B. Dressler *et al.*, Eur. Phys. J. C**14** (2000) 147.

[4] S. Vigdor, 'The RHIC Spin Program: Snapshots of progress', Invited talk at the 13^{th} International Symposium on High-Energy Spin Physics (SPIN98), Provino, Russia.

[5] STAR Collaboration, 'The STAR decadal upgrade plan', presented to the BNL management, September 2003; Brookhaven National Laboratory and RHIC Community, 'Twenty-Year Planning Study for the Relativistic Heavy Ion Collide facility at Brookhaven National Laboratory', presented to the U.S. Department of Energy, Office of Nuclear Physics, December 2003, BNL-71881-2003.

[6] P.M. Nadolsky and C.-P. Yuan, Nucl. Physcs. **B666** (2003) 31.

[7] M. Glück et al., Phys. Rev. **D57** (1996) 4775.

[8] M. Karliner and R.W. Robinett, Phys. Lett. **B324** (1994) 209.

[9] I. Bojak and M. Stratmann, Phys. Rev. **D67** (2003) 034010.

[10] STAR Collaboration, 'The STAR decadal upgrade plan', presented to the BNL management, September 2003; Brookhaven National Laboratory and RHIC Community, 'Twenty-Year Planning Study for the Relativistic Heavy Ion Collide facility at Brookhaven National Laboratory', presented to the U.S. Department of Energy, Office of Nuclear Physics, December 2003, BNL-71881-2003.

[11] U. Becker, B. Tamm and S. Hertel, Nucl. Instr. Meth. **A 556** (2006) 527.

[12] C. Altunbas et al., Nucl. Instr. Meth. **A 490** (2002) 177.

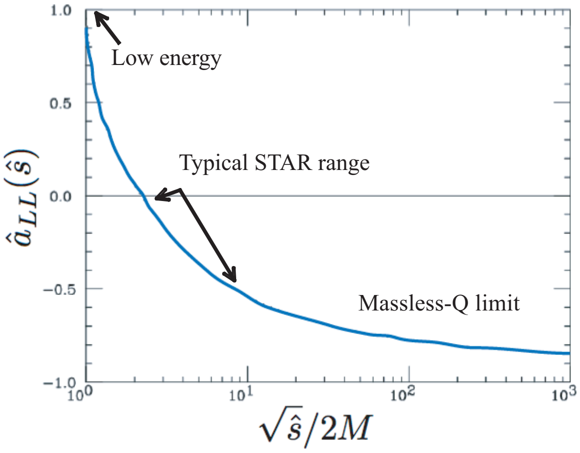

Figure 1: *Partonic double-longitudinal spin asymmetry as a function of* $\sqrt{\hat{s}}/2M$*. The range covered by the RHIC kinematics in case of* $M = m_c$ *(charm mass) for* $\sqrt{s} = 200 - 500$ *GeV is shown together with the low energy and massless quark limit [8].*

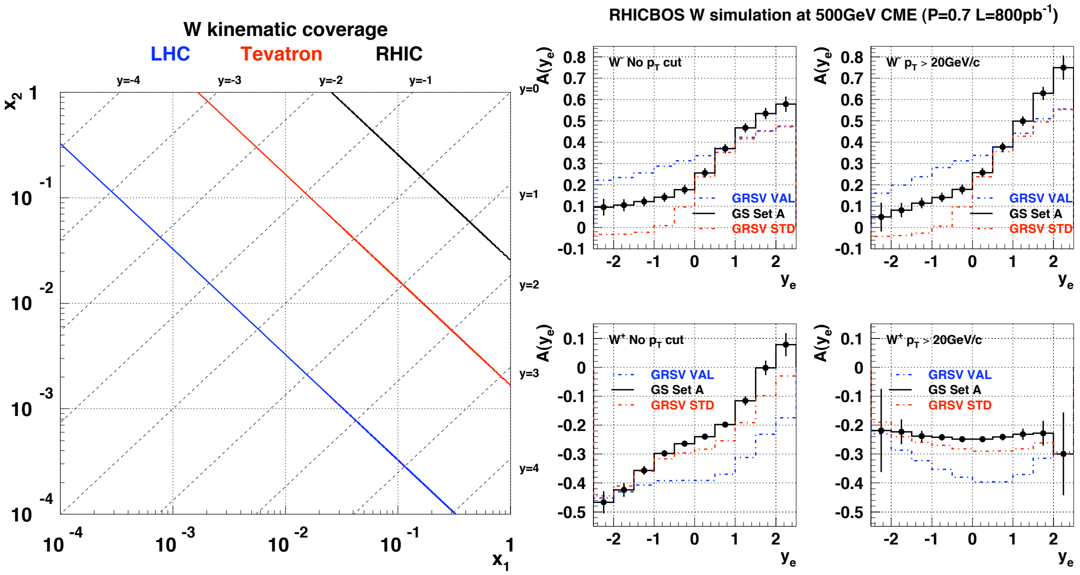

Figure 2: *W kinematics in terms of the partonic Bjorken x_1, x_2 and lepton rapidity y of the RHIC coverage at $\sqrt{s} = 500\,GeV$ in comparison to the Tevatron ($\sqrt{s} = 1.96\,TeV$) and LHC ($\sqrt{s} = 14\,TeV$) (left). RHICBOS [6] simulation of leptonic single-longitudinal spin asymmetry as a function of lepton radidity comparing three different sets of polarized distribution functions (right).*

Fiscal year	Required funding k$	Remarks
2008	50	Barrel Sensor R&D batches
	50	Barrel Sensor R&D batches
	25	Barrel Hybrid R&D batches
	50	Barrel Prototype cables
	25	Barrel Hybrid R&D batches
	40	Barrel misc. items
	100	Barrel Hybrid order
	134	Barrel APV25 chip order
	40	Barrel misc. items
Total FY08	514	
2009	894	Barrel Sensor order
	1000	Barrel mechanics
	1032	Barrel cables, FEE, Integration FEE/DAQ,
		Power supply and Cooling
Total FY09	2926	
2010	532	Barrel cables, FEE, Integration FEE/DAQ,
		Power supply and Cooling
	100	Forward disk Sensor R&D batches
	25	Forward disk Hybrid R&D batches
	25	Forward disk Prototype cables
	375	Forward disk Sensor order
	50	Forward disk Hybrid order
	45	Forward APV25 chip order
	150	Forward mechanics
	60	GEM foil order
	25	GEM Hybrid R&D batches
	25	GEM Prototype cables
	120	GEM Hybrid order
	15	GEM APV25 chip order
	100	GEM chamber mechanics
	50	Forward disk misc. items
	20	Barrel misc. items

Table 4: Preliminary funding profile starting from fiscal year 2008 until fiscal year 2011.

Fiscal year	Required funding k$	Remarks
2010	300	Forward disk Sensor order
	48	Forward disk Hybrid order
	40	Forward APV25 chip order
	150	Forward mechanics
	880	Forward disk cables, FEE, Integration FEE/DAQ,
		Power supply and Cooling
	60	GEM foil order
	120	GEM Hybrid order
	15	GEM APV25 chip order
	150	GEM mechanics
	275	GEM cables, FEE, Integration FEE/DAQ,
		Power supply and Cooling
	50	Forward disk misc. items
	50	GEM misc. items
	600	Labor cost
Total FY10	4405	
2011	60	GEM foil order
	124	GEM Hybrid order
	10	GEM APV25 chip order
	150	GEM mechanics
	275	GEM cables, FEE, Integration FEE/DAQ,
		Power supply and Cooling
	50	GEM misc. items
	300	Labor cost
Total FY11	969	
Total FY08-FY11	8400	

Table 5: Preliminary funding profile starting from fiscal year 2008 until fiscal year 2011.

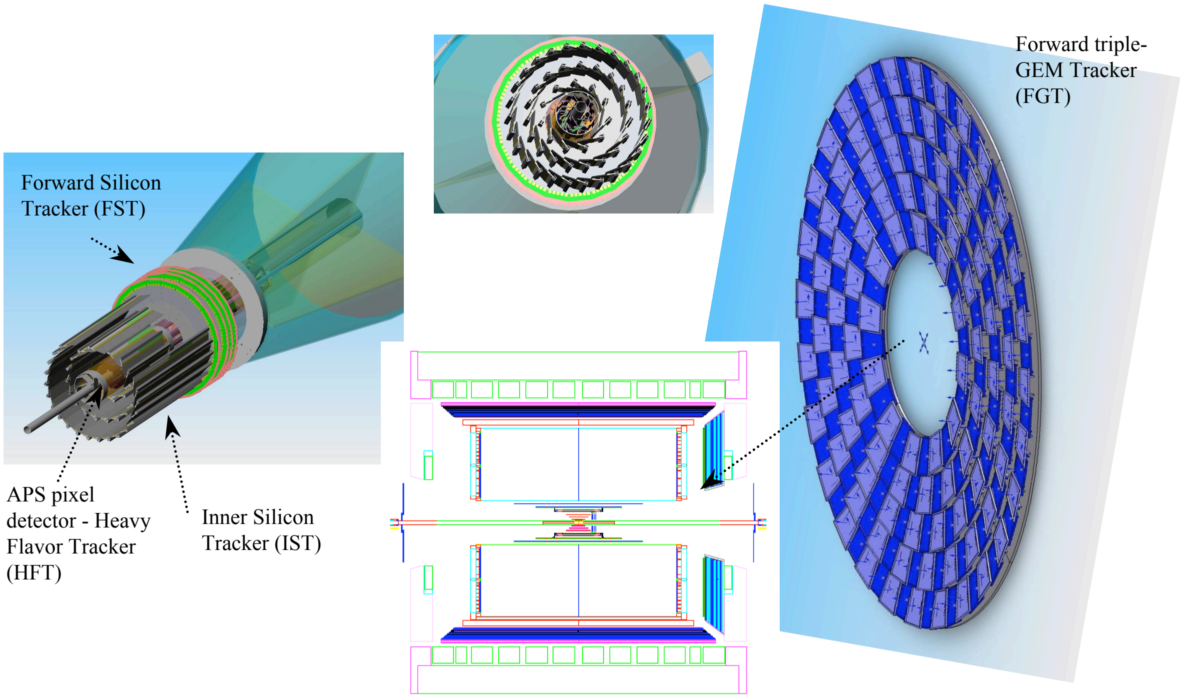

Figure 3: *Side view of the GEANT simulation (center). The engineering design of a triple-GEM based tracking system (Forward-GEM Tracker: FGT) in front of the STAR ElectronMagnetic Endcap Caloprimeter (EEMC) is shown on the right side. The engineering layout of a new inner-barrel (Inner-Silicon Tracker: IST) and forward-disk (Forward-Silicon Tracker: FST) silicon tracking system is shown on the left side. The inner-two barrel layers based on an Active-Pixel Sensor Detector (Heavy-Flavor Tracker: HFT) are shown in the upper center figure surrounded by three IST barrel layers.*

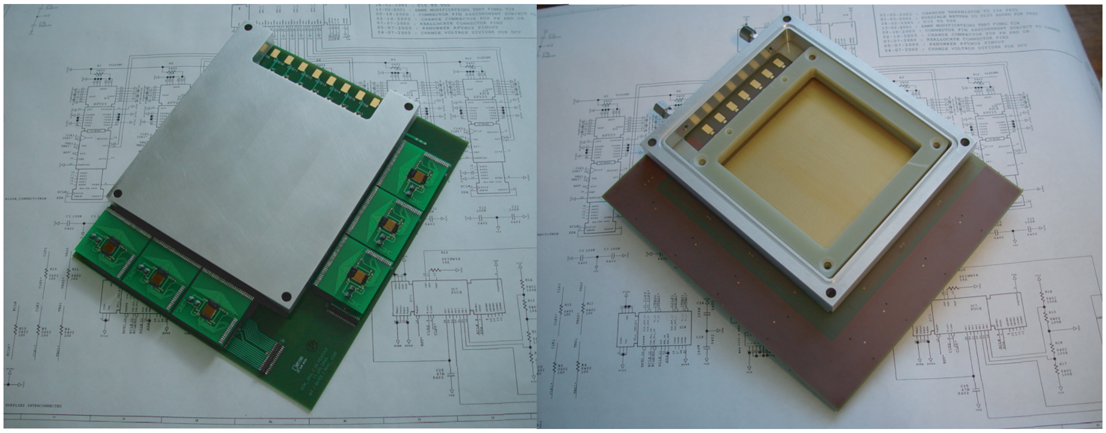

Figure 4: *Bottom (left) and top (right) view of the prototype triple-GEM chambers. The location of the sensitive detector volume can be clearly seen on the right side with the location of three inner G10 carrier frames. No GEM foils have been glued onto the frames shown. The location of groups of three readout hybrids can be clearly seen on the left side.*

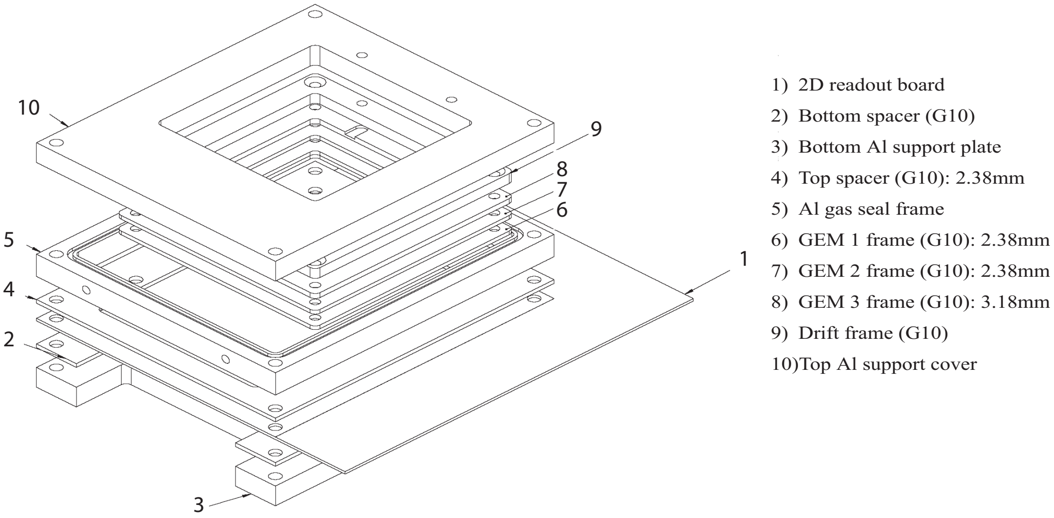

Figure 5: *Exploded view of a prototype triple-GEM chamber indicating the location of various chamber elements.*

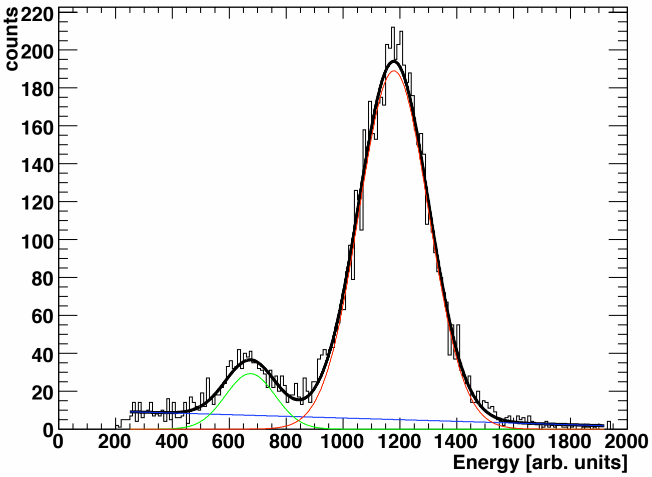

Figure 6: ^{55}Fe spectrum recorded with a triple GEM prototype based on CERN foils. The full-energy photo peak and the argon escape peak are cleanly separated. The spectrum is fitted with two gaussians and a linear background. The energy resolution of the photo peak is ~20%, given by the FWHM of the peak.