STAR Upgrades R&D Proposal
FY 2003 – FY2005

Prepared by the STAR Collaboration
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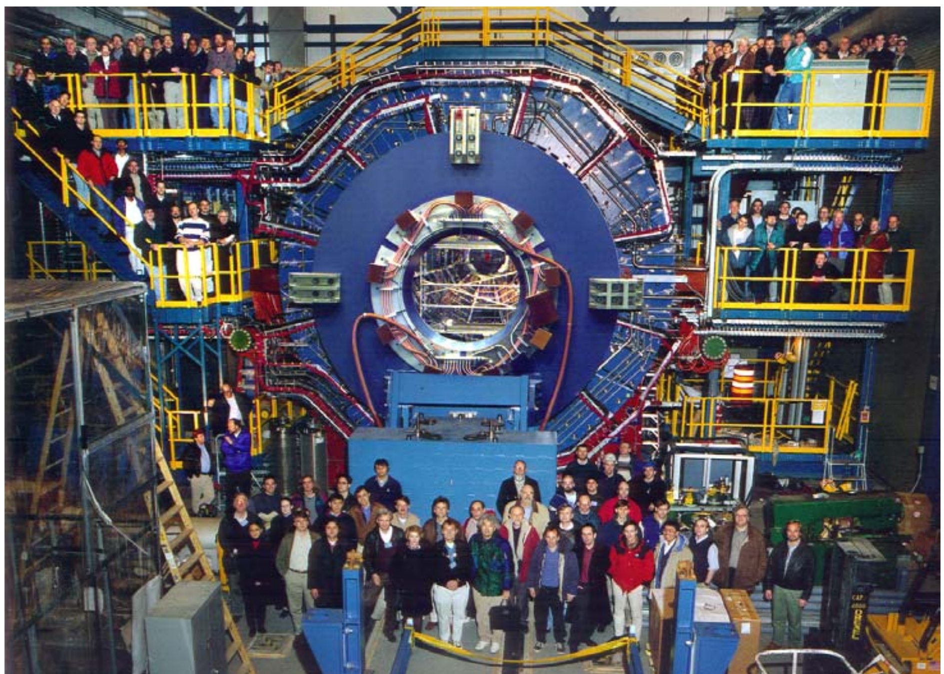
I. Overview: Physics goals and upgrade plans

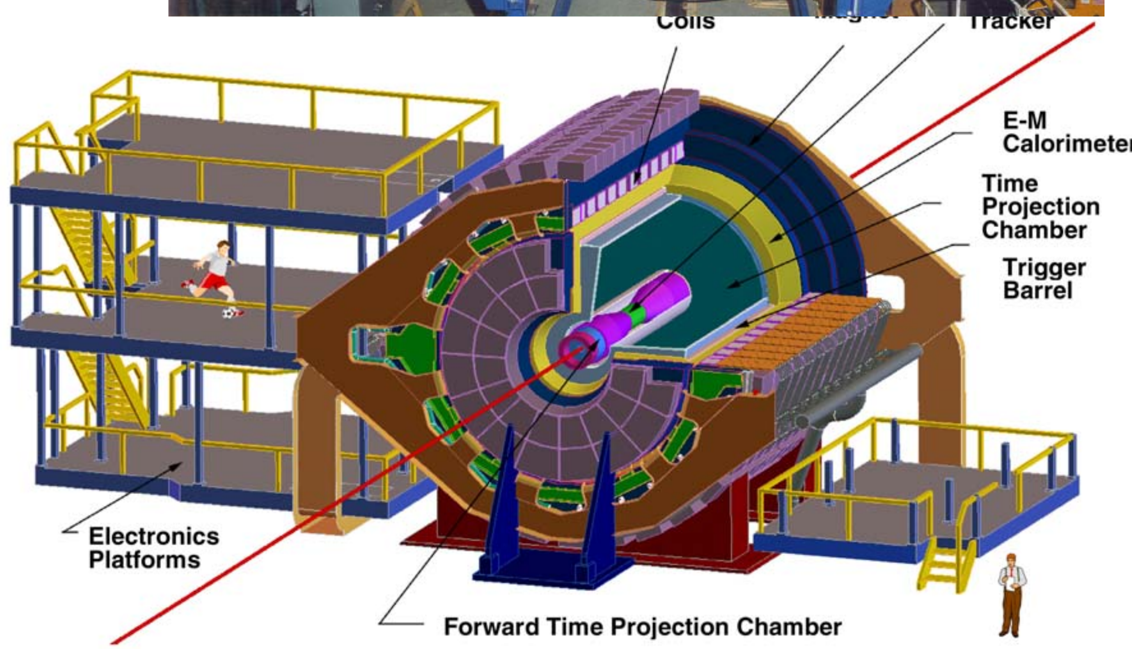
The STAR detector was designed and implemented to provide an instrument of great power for exploring new phenomena in the complex environment of heavy-nucleus collisions at c.m. energies ten times greater than any previous laboratory experiment. Its main feature is the ability to measure particle production with full azimuthal acceptance over a significant interval of central rapidity with excellent capability for tracking and particle identification.

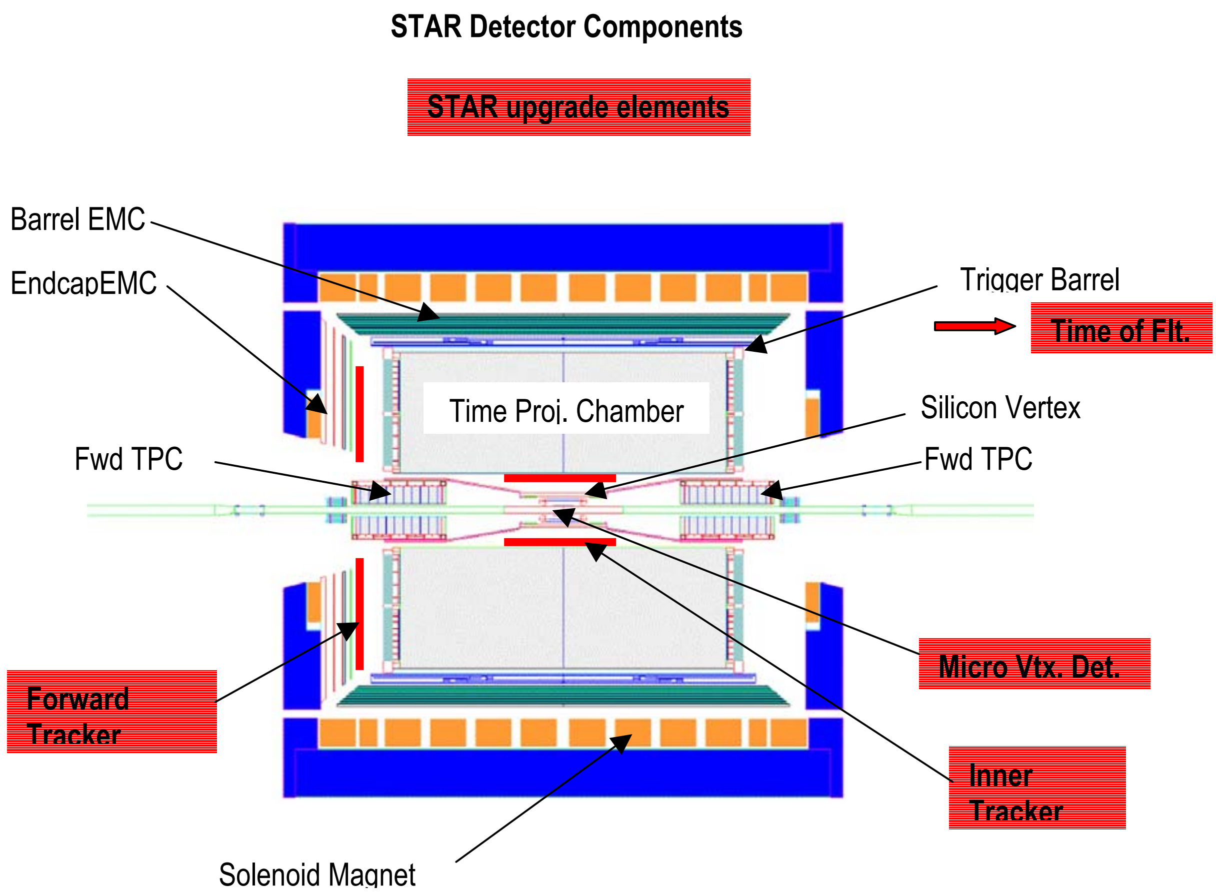
During the first two RHIC runs, the resolving power and wide angular coverage of the STAR detector has provided not only a broad view of the global features of the new physics landscape, but also sensitive measures of particle production that have quickly brought the RHIC investigations to the heart of the scientific questions regarding the formation of new forms of matter in heavy ion collisions. These include the discovery and detailed measurement of strong collective flow effects, indicative of elliptical and radial flow at near-hydrodynamic values; measurements of meson and baryon particle and antiparticle spectra, including strange mesons, resonance states, and multistrange hyperons, revealing a well-constrained consistency of the data with models based on interacting matter in thermal and chemical equilibrium; the first 3-D "pictures" of the space-time evolution of matter utilizing two-particle interferometry, showing surprisingly small values for the freezeout volume, perhaps indicating the rapid disintegration of a hot, thermal source; the study of non-statistical event-by-event fluctuations over large solid angles, with small systematic errors; and measurements of particles at high transverse momentum to test the dynamics of hard partons in the high-density medium of RHIC collisions. In the last of these items, STAR, as well as PHENIX, have already begun to explore high p_t physics, with spectra reaching out to ~10 GeV/c in the recent 200 GeV/nucleon Au-Au data sample. STAR has shown the first direct evidence for jet production in high energy collisions of heavy nuclei, and both experiments are deeply engaged in analyzing the observed suppression of the rate of high-p_t hadron emission relative to that seen in nucleon-nucleon collisions – a predicted effect of parton energy loss in a deconfined medium.

Since beginning operation, the STAR detector has continued to evolve. The Silicon Vertex Tracker and Forward Time Projection Chambers were implemented in 2001, as were the first 24 modules of the Barrel Electromagnetic Calorimeter (20% of the full barrel). For the FY 2003 RHIC run, one-half of the Barrel Electromagnetic Calorimeter (BEMC) will be installed, as well as the first segments of the Endcap EMC. These calorimeters, which will be completely implemented for the FY 2005 run, give STAR a powerful, large solid angle, fine-grain EM calorimeter system capable of providing fast signals at the earliest trigger level. The STAR Data Acquisition system, initially foreseen to record the most complex events at a rate of ~1 Hz, is presently capable of recording ~10 central Au-Au events per second. For the FY 2003 run, improvements to the DAQ will allow processing of 100 central events per second (for presentation to the Level 3 trigger), and a recording rate of ~30 Hz. As discussed below, a further increase of the DAQ processing rate and the readout speed of the TPC by an order of magnitude is a key part of the STAR upgrade plan.

Views of the STAR Detector






STAR Detector Components
STAR upgrade elements
Barrel EMC
EndcapEMC
Trigger Barrel
Time of Flt.
Time Proj. Chamber
Silicon Vertex
Fwd TPC
Fwd TPC
Micro Vtx. Det.
Forward Tracker
Inner Tracker
Solenoid Magnet

Overview: Physics goals and upgrade plans

The STAR collaboration has recently submitted a 3-year Beam Use Proposal (www.star.bnl.gov/STAR/smd/bur_fy03.pdf) that lays out the plan to continue the first phase of its measurement program. It is expected that this phase will complete the steps necessary for a definitive identification of the quark-gluon plasma and the initiation of the RHIC spin measurements. Already a great deal has been learned about the physics of high energy heavy ion collisions, and much discussion has taken place within the scientific community regarding the next stage of exploration and discovery in this qualitatively new realm for observing QCD interactions. The opportunity exists for detailed exploration of the phases of strongly interacting matter as extended volumes evolve from an initial state of very high energy density, through an equilibrated plasma, to final freeze-out as hadrons. The scientific goals that drive the upgrade path for the STAR detector are most recently summarized in the report of the June 2002 Bar Harbor Workshop, "STAR Future Physics and Detectors" www.star.bnl.gov/STAR/meetings_l/collab_l/future/workshop.html .

With staged detector improvements, and enhanced RHIC luminosity, STAR expects to take a lead role in these key programs for future experimentation at RHIC:

<u>Measure the essential properties of the quark-gluon plasma:</u>

- Gluon density of the plasma through high p_t studies of jet quenching…
  - Jets tagged in coincidence with high p_t photons provide "beams" of high energy partons to probe the plasma. *Significant samples of photon-tagged jets at transverse momenta well into the perturbative regime (≥10 GeV/c).*
  - Quark mass dependence of energy loss via identified heavy-quark jets.
- Large-statistics measurements of partonic collectivity through correlations among light-, strange-, and charmed-quark states *(e.g. participation of heavy quarks in flow as a probe of the thermal evolution of the plasma).*
- Direct photon spectra via γγ HBT*, providing a unique measurement of QGP temperature, size, lifetime via electromagnetic radiation.*

<u>Explore the early phases of reaction dynamics in QCD matter formation:</u>

- Precision studies of high p_t and high mass observables, including Drell-Yan spectra, calculable in perturbative QCD. *Studies of Drell-Yan spectra in the 5-10 GeV range, and jet transverse momentum spectra reaching beyond 30 GeV/c.*
- Open beauty, charm spectra at high p_t . *Large samples of tagged jets with identified heavy-quark flavor.*
- Direct photons as probes of saturated gluon phase at very early times. *Samples with transverse momenta >20 GeV/c.*

<u>New phenomena in bulk QCD matter:</u>

- Studies requiring very large samples of unbiased data (>10^8 events); for example, Search for strong CP violation associated with deconfining phase transition in heavy ion collisions as predicted by Kharzeev et al..

The broad strategy for upgrading the STAR detector to make these measurements possible over the next decade is two-fold:

1. **Upgrade the readout and data acquisition electronics, and the Level 3 trigger capability, to allow an event rate to Level 3 of at least 1000 central Au-Au per second, and to record such events at a rate of at least 100 Hz.**

2. **Enhance the detector complement to include high-momentum particle identification over large solid angle (Time-of-Flight Barrel) and the capability to directly resolve the decays of charm particles, and tag heavy quark jets (Microvertex Detector).**

3. **Improve the high-rate tracking capability and develop the technology for eventual replacement of the Time Projection Chamber (Micropattern TPC read-out technology).**

A central element of the planning for the future of STAR is the performance of its primary tracking detector, the Time Projection Chamber (TPC) with increasing luminosity. Studies of this detector, and analysis of its performance during the first two RHIC runs, have confirmed that the TPC is well suited to the STAR measurements, and will remain so through the rest of this decade. The large solid-angle coverage, excellent track resolution, robust pattern recognition, and good dE/dx capability have proven a powerful combination for quickly extracting a wide range of new physics from the most complex collision events. The TPC will support the high-rate operation proposed for the STAR upgrade, as it should be possible to operate the gated grid at upwards of 1000 Hz without ion feedback from the anodes. The TPC is not expected to suffer significant loss of efficiency or resolving power as the Au-Au collision rate increases up to 4 x design value. Detailed studies, involving measurements and simulations, are being carried out to ensure that the required performance at high rate and increased luminosity can be achieved.

Nonetheless, STAR should prepare for the eventual replacement of the TPC in the time-frame beyond 2010. At the luminosity achievable with electron-beam cooling in RHIC, up to 40 x design value, an intrinsically faster tracking detector will be required.

The net result is that STAR sees no compelling reason to replace the TPC during the period between now and 2010. R&D work should proceed, with high priority, on the technology for an eventual replacement. At present the best candidate appears to be the micropattern TPC [GEM] readout technique being jointly developed by STAR and PHENIX. STAR is planning to develop a small cylindrical TPC, with GEM readout, to fit inside the inner radius of the present TPC ($R \sim 50$ cm). This would bolster the present TPC at the inner radii, where the effects of increased luminosity are most strongly felt, and would serve as a prototype for a larger device that could eventually replace the TPC.

In the paragraphs below we give brief descriptions of the candidate upgrades for STAR. These are all presently under development within the collaboration, and their relationship to the essential physics goals were most recently discussed at the workshop on STAR Future Physics and Detectors, June 17-21, 2002, in Bar Harbor, Maine. The descriptions below give the respective roles of these upgrades in the STAR physics program, and the R&D proposals that follow present the development effort required for the practical realization of these projects.

High-rate upgrades for Front End Electronics and Data Acquisition System: The STAR detector is currently limited to a processing rate of ~10 central Au-Au events per second. Improvements to the DAQ system are now being implemented to increase this to ~100 Hz for the next run. This is presently a hard upper limit imposed by the readout electronics of the TPC, FTPC and SVT. For the STAR upgrade these front-end electronics would be replaced, with the goal of increasing the processing rate for events at Level 3 to >1000 Hz for Au-Au central. The CERN/ALICE front end TPC chip is in the final stages of development, and could be implemented in STAR for this purpose. In order to accomplish this, along with the upgrades to the DAQ electronics, a significant development and engineering effort needs to be initiated during the coming year.

Trigger: The present trigger architecture of STAR is capable of dealing with the planned luminosity upgrades for RHIC, but new, fast detectors will need to be incorporated. Examples include the barrel TOF, to replace the Central Trigger Barrel with higher granularity, and a high resolution Vertex Position Detector. A significant upgrade of the Level 3 trigger will be required to take advantage of the enhanced readout and DAQ rates while maintaining a manageable recording rate.

Barrel Time-of-Flight Detector: This would extend K/p separation to ~3 GeV/c over nearly the full acceptance of the TPC and the barrel calorimeter. This will greatly enhance the p_t range and sensitivity for all studies of flavor-dependent phenomena, and is pivotal for many of the studies outlined above. A proposal to build this detector, using resistive plate chamber technology, is presently being reviewed within the collaboration, and a prototype is being readied for installation in STAR for the coming run. R&D is required for final design and prototyping of the readout electronics. The physics value of such a detector becomes greater the sooner it is available, and an effort is being made to initiate it as a joint U.S.-China effort, to begin in FY 2004.

Microvertex Detector: Providing ~10 μm resolution for tracks near to the collision point, such a detector is essential for the study of open charm and beauty, and for c- and b-quark jets via displaced electrons. This device, too, would be of immediate benefit to the program and should be implemented as soon as possible. The LBL group (H. Wieman) is studying the Active Pixel Sensor (APS) technology developed at LEPSI. The CERN/ALICE approach using hybrid pixel devices is further along in development, and is being actively pursued by PHENIX as a "fast track" solution for a high resolution inner vertex detector. It has the disadvantage of requiring a lot of material in the innermost tracking region. The present APS devices have readout that is too slow for the full RHIC II luminosity; this is expected to improve with development effort. A phased approach is possible whereby a first-generation APS detector is installed on a fast track, and replaced later. This is an area where STAR and PHENIX have shared R&D interests.

Micropattern TPC Readout (GEM): These devices are presently the object of a joint R&D effort with STAR and PHENIX, and are being extensively developed in the CERN community. They offer the possibility of a compact TPC with very fine granularity and high spatial resolution. With this technology it appears possible to replace the functionality of the present TPC with a device of much smaller volume, hence shorter drift distance, and thus mitigating the problems of space-charge build-up and pileup. This development should continue with a high priority for STAR. A possible strategy is to plan for an "Inner Tracker" using GEM technology that would provide high-rate tracking capability in a cylinder just inside the inner radius of the present TPC. This would improve the tracking capability at 4 x design luminosity, and serve as a prototype for an eventual full TPC replacement. Micropattern readout technology could also be used to provide a "Forward Tracker" in front of the Endcap EMC, improving the resolution for high momentum tracks that don't traverse the full radius of the TPC. This would be especially important for the spin program where, for example, it is vital to resolve the sign of the charge of high-momentum electrons from W decay.

Proposed R&D Projects

The R&D effort required to carry out this upgrade plan is described in the sections that follow. These are presented as separate proposals, each with its own Principal Investigator and supporting institutions from within the STAR collaboration. The proposed effort is summarized in the table below.

			Requested Funds (K$)		
Project	Principal Investigator	Collaborating Institutions	FY 2003	FY 2004	FY 2005
TPC FEE Upgrade	J. Marx	LBNL	79.8	166.5	0.0
DAQ Upgrade	T. Ljubicic	BNL	207.0	716.0	850.0
MRPC Time-of-Flight Development	G. Eppley	Rice	128.0	134.0	0.0
High Resolution Vertex Detector Development	H. Wieman	LBNL, BNL	133.3	336.5	495.0
Micropattern Readout Development for Gas Detetectors	N. Smirnov	Yale, BNL, LBNL	210.0	347.0	347.0
		Totals	758.1	1700.0	1692.0

II. Proposal for STAR TPC FEE Upgrade R&D

Principal investigator: Jay Marx (LBNL)
Lead Engineer: Fred Bieser (LBNL)

In the coming years, it is expected that the RHIC Collider will provide increasing luminosity to allow the existing experiments to gain access to new physics opportunities. Upgrades to the STAR detector commensurate with the improvement of the RHIC luminosity will allow the STAR Collaboration to extend the physics reach of STAR via studies of rare processes and of phenomena
that can be resolved only through analyses of very large unbiased event samples. In each of these aspects the combination of high event rates and the inherently large solid-angle coverage of STAR will provide a powerful instrument for exploiting the next phase of RHIC as a "Nuclear QCD Machine".

An essential goal of the STAR Upgrade program is to achieve a 1 kHz event transfer rate to the level 3 trigger.

Even without an increase in the luminosity of the RHIC collider, this capability would have a very significant physics payoff. For those event categories satisfying STAR's lower level triggers at a rate above the current maximum TPC/DAQ readout capability, the 1 kHz upgrade would mean reduced effective dead-time and so an effective luminosity increase for STAR. For example, in the case of minimum bias events which occur at greater than a kHz at the present luminosity, rare configurations which can be identified by the level 3 trigger would be collected by STAR's at an order of magnitude higher rate per unit RHIC luminosity then at present.

Achieving a 1 kHz event transfer rate to the level 3 trigger requires that the TPC readout be able to present event data to the DAQ input at a rate, which is an order of magnitude higher than the present 100 Hz rate. Achieving this requirement will require replacing the present TPC front-end electronics (FEE) with a higher bandwidth system that can accomplish zero suppression and other data compression before data is presented to the DAQ. We note that the TPC gated grid will be able to cycle at 1 kHz as would be required.

Preliminary studies indicate that it may well be possible to develop a new TPC FEE based on the ALTRO FEE chip developed for the ALICE TPC. The ALTRO is a 16-channel analog/hybrid chip with ADCs and DSP subcores on the chip. It accomplishes pedestal subtraction, gain correction, baseline restoration/filtering, zero suppression and on chip buffering for 8 events.

This proposal is targeted at the preliminary scientific and engineering evaluation needed to define the science-driven requirements and engineering specifications for the

TPC FEE upgrade and to evaluate the ALTRO chip and other possible technical alternatives for achieving a viable TPC FEE upgrade.

In the first year of the R&D period, the science-driven requirements will be determined, the ALTRO chips and other possible technical approaches will be evaluated, and a specific technical approach will be chosen that can deliver the science-driven requirements.

In the second year, detailed simulations to support the pre-conceptual design will be completed, and four 64 channel prototype 1 kHz FEE cards and associated readout electronics will be used to instrument a spare TPC inner and a spare TPC outer sector for detailed testing and evaluation of this prototype system. Also the preliminary design documents needed to support rapid construction will be completed.

This work will form the basis for a rapid turn-on of construction of the TPC FEE upgrade immediately following the completion of this R&D task.

This R&D task will require both engineering and scientific personnel and will be accomplished in a period of approximately 2 years.

The table below, indicates the deliverables for each year and the resource that will be needed to accomplish this R&D task:

<u>Year 1:</u>

Deliverables

1. Evaluation of suitability of ALTRO chip
2. Development of science driven requirements
3. Evaluation of alternate approaches
4. Decision on technical approach

Personnel

Senior Electrical Engineer	25% FTE	(provided from LBNL base
Senior Physicist-	25% FTE	(provided from LBNL base)
Post-doc	50% FTE	(supported with R&D funds)
Total personnel	1 FTE	

Travel, purchases and subcontracts

Travel	$5k
Purchases- misc. parts; test equip.	$10k
Subcontacts- for board assembly-	$10k
total non-personnel costs	$25k

Year 2:

Deliverables
1. Simulations supporting pre-conceptual design
2. Existing spare TPC sectors instrumented with four 64 channel cards of prototype 1 kHz FEE and associated readout
3. Test results and performance evaluation from instrumented inner and outer sector
4. Preliminary design documents to support rapid construction

Personnel

Senior Electrical Engineer	50% FTE	(provided from LBNL base)
Junior electrical Engineer	50% FTE	(supported with R&D funds)
Physicist-	50% FTE	(provided from LBNL base)
Post-doc	50% FTE	(supported with R&D funds)
Total personnel	2 FTE	

Travel, purchases and subcontracts

Travel	$5k
Purchases related to prototypes for instrumented inner sector	$15k
Subcontracts related to prototypes for instrumented inner sector	$25k
total non-personnel costs	$45k

The Table below summarizes the anticipated costs for this R&D task:

Category	Description/comments	FY 2003K$	FY 2004 K$	FY 2005 K$
Salaries (Includes fringe)	Only for personnel supported from R&D funds (postdoc, jr. electrical engineer)	$32.6k	$71.8k	Two year project
Travel	CERN related to ALTRO chips; Brookhaven to interface with DAQ upgrade R&D effort	$5k	$5k	Two year project
Purchases	See text above	$10k	$15k	Two year project
Subcontracts	See text above	$10k	$25k	Two year project
Overhead costs	Only for personnel supported from R&D funds (postdoc, jr. electrical engineer)	$22.2k	$49.7k	Two year project
Total		$79.8k	$166.5k	Two year project

III. Proposal for STAR DAQ Upgrade R&D, FY 2003 to FY 2004

Principal Investigator: Tonko Ljubicic, BNL

At the STAR Future Upgrades Meeting, June 2002, Bar Harbor, the STAR collaboration expressed a requirement stating DAQ data rates with the TPC on the *order of 1 kHz*.

The current STAR DAQ system is a hierarchically organized system of VME crates connected with a fast Myrinet network. Each crate typically corresponds to a detector or a sub-detector (i.e. a TPC sector) and houses detector specific Receiver Boards. Each Receiver Board holds 3 daughter boards each with an Intel I960HD CPU and 6 STAR-DAQ ASICs to facilitate data formatting as well as preprocessing for the Level III trigger (*cluster finding*). The Receiver Boards for the TPC, SVT, FTPC & SSD are all the same and were custom designed and manufactured.

This system has several bottlenecks due to the original requirements of storing one event per second but being able to analyze 100 events per second into a Level III Trigger farm. The major bottlenecks are: the slow CPU on the daughter boards (66 MHz), the fixed throughput of 100 Hz at the fiber optical input to the Receiver Boards and finally the relatively low bandwidth of the standard VME64 crates (about 40 MB/s). Other bottlenecks are in the architecture of the Event Builder as well as in the Level III processing cluster both of which need to be resized in a scalable manner.

Current DAQ/detector rates are limited to about 50 Hz in the DAQ domain and 100 Hz in the TPC domain. These are *hard* limits and they *cannot be increased* without a *simultaneous* redesign of *both* the DAQ system and the TPC front-end electronics. An incremental upgrade is not possible due to many constraints internal to the current system such as custom ASIC limits, CPU speed limits, network limits etc. A new design with new electronics, computing power and faster network/bus interconnects is necessary.

Increasing the DAQ rates by a *factor of 10 to 20* is a significant challenge and thus necessitates a considerable and well focused Research & Development program.

The main prongs of this R&D would concentrate on

a) STAR-specific data compression computing technology
b) fast interconnect(s) between subparts of the DAQ system
c) the computing technology used for the Level III trigger decision based upon the tracking detector's (assumed to be TPC but need not be) data.
d) computer technology enabling high-rate data aggregation ("Event Building") for further storage

This proposal assumes the STAR TPC as the largest source of data as well as the tracking detector for Level III algorithms. We however plan to design the DAQ upgrade to be independent of the data source as much as possible. Such a design strategy facilitates an eventual change in the basic detector technology in the years to come. Additionally, the developed upgrades will take into account the other current STAR detectors such as SVT, FTPC, EMC etc.

Data Compression Computing Technology

The current STAR DAQ contains about 450 microprocessors managing just the TPC data alone. The most important task these CPUs have is the two-dimensional cluster finding as the important step towards a large data reduction scheme. The current CPUs are Intel I960HD running at 66 MHz and they can handle about 50 Hz of central Au-Au collisions. Increasing this rate by 20 times (to 1 kHz) requires a search for a new processing element which in our view can either be a much faster CPU, a DSP, an FPGA or some combination of the above. Evaluating these technologies is the first step in the process of speeding up the whole system.

Fast Interconnects

The current STAR DAQ system containing the industry-standard VME crates as well as 1 GHz optical connections to the TPC front-end is capable of moving about 100 Hz worth of TPC data. To increase this volume by a factor of 10 a new interconnect technology is necessary, taking advantage of new technology developments on the ten years since the original STAR design. The R&D resources have to be spent evaluating the current cutting-edge networks as well as the board-to-board and chip-to-chip communication paths.

Level III Computing

STAR's Level III computing cluster currently contains about 50 commercial workstations which can handle about 50 Hz central Au+Au collisions. Simply increasing the number of computers to ~1000 to meet the 20 times increase may not be desirable due to per-event latency considerations.

It is necessary to re-evaluate the CPU technology as well as the network interconnecting the future nodes to the rest of the DAQ processing chain. Additional development of the fast tracking software will also be required to better match the required physics performance with the underlying hardware.

In any case, the number of nodes will need to be considerably larger than the current cluster size, and new commercial techniques for packaging, cooling, and management need to be evaluated on a cluster of moderate size before a final design can be seriously specified.

High-rate Event Building

The Event Building is the last stage of the STAR DAQ system and currently can handle about 50 Hz of central Au+Au collisions deploying a large computer workstation with a significant amount of disk and memory. Such a single-station topology can't scale a factor of 20 even assuming future CPU, memory and storage improvements. The only currently known cost-effective approach to this scaling problem is the use of a cluster of high performance workstations working in event-parallel mode. We propose to build a small scale system and evaluate its performance and scalability with current technologies which we can then scale both in performance and price as the construction phase of the project commences.

Since all of these parts would work together as a whole system and are tied together with common interconnects we propose one R&D project to handle these tasks at the same time.

R&D Stages:

The R&D effort is assumed staged into three phases matching the Fiscal Years 2003 through 2005.

1) FY2003 Technology Survey

In the first year of this project we plan to evaluate technologies for all the above components using commercially available products. This would mean survey of existing technologies, purchase of vendor-specific development products and platforms, performance evaluation and measurement, code adaptation to differing environments (i.e. implementing the cluster-finding software in FPGAs). For the Level III and Event Builder components we would purchase and evaluate the fastest computers on the market deemed capable and cost-effective for the final design.

A part of the effort would be spent integrating possible technological choices with the new TPC front-end.

Technical Personnel:

Electrical Engineer .5 FTE (provided from BNL base)
Electrical Engineer .25 FTE (supported with R&D funds)

2) FY2004 Subprototypes

The second phase would be spent in the design and test of small custom-made units which mock-up the full DAQ chain. I.e. we expect to have a well designed TPC front-end interface by that time and we would spend the effort attempting to evaluate a single vertical slice of the full parallel readout chain.

We expect to have a good understanding of the bottlenecks of the proposed system as well as the Level III farm and the Event Building strategy.

Technical Personnel:

Electrical Engineer 1 FTE (provided from BNL base)
Electrical Engineer 1 FTE (supported by R&D funds)
Electrical Tech. 1 FTE (provided from BNL base)

3) FY2005 **Final Prototype**

The last year will be spent designing and manufacturing the full prototype of a concrete DAQ chain including all the specific interconnects and computing elements. We expect to fully test and debug such a chain as well as measure its performance. By the end of this stage we expect to be prepared for the construction phase of the project where we would manufacture and replicate the processing units based on this final prototype.

Technical Personnel:
- Electrical Engineer 1 FTE (provided from BNL base)
- Electrical Engineer 1 FTE (supported by R&D funds)
- Electrical Tech. 1 FTE (provided from BNL base)

Budget Estimate

Category	Comments	FY2003 k$	FY2004 k$	FY2005 k$
Salaries	Assumes 120 k$/engineer; 90 k$/technician.	23 (1/4 engineer)	120 (1 engineer)	120 (1 engineer)
Travel		20	10	10
Purchases		100	300	400
Subcontracts	PCBs…	10	100	100
Overhead	Assumed 35%	54	186	220
Total		***207***	***716***	***850***

Scientific Support:

Jeff Landgraf (BNL)
Micheal LeVine (BNL)
Tonko A. Ljubicic (BNL) *Principal Investigator*
David Lynn (BNL)

IV. MRPC Time-of-Flight Development

Principal Investigator: Geary Eppley (Rice)
Lead Engineer: Lloyd Bridges (Rice)
STAR TOF Group http://mac8.rice.edu/~TOF/TOF.pdf page 1

Introduction:

The design philosophy of the STAR detector, unique among RHIC experiments, is to create a large-acceptance detector capable of measuring and identifying a substantial portion of the particles produced in a heavy-ion collision. The powerful statistical technique of multi-particle correlations can then be used to explore the dynamics of high-multiplicity events, event-by-event physics. In particular, a large-acceptance TOF system, envisioned from the inception of the STAR project, will yield particle identification and probe the flavor composition of events. STAR will gain access to new event-by-event observables that can be used to distinguish global color-deconfinement dynamics from string fragmentation and hadronic re-scattering. This is the primary goal of the RHIC project. The study of elliptic flow at higher momentum, resonance production, baryonic densities, and open charm production will all be greatly enhanced and each is necessary to complete our understanding of the dynamics on nucleus-nucleus collisions.

The original design goal of the STAR detector has yet to be fully realized. Proposals for a full barrel TOF for the central region |eta|<1 now occupied by the CTB were not included in the baseline detector since the cost of a 6k channel scintillator T0F system using ~$1.5k mesh-dynode PMTs was prohibitive.

The October 2000 STAR Long Range Plan reiterated the original design goal and established the completion of the calorimeters and the construction of a large-acceptance TOF system as the highest near-term priorities. The 1996 NSAC subcommittee noted: "... STAR should aim at a [TOF] coverage which is sufficient for event-by-event kaon (and possibly proton) identification, which in other observables is the prominent feature and strength of STAR. If fiscal constraints are such that this cannot be realized, ...further R&D should be encouraged to search for a viable solution for large area coverage."

We believe we have found a viable solution. A new technology was developed at CERN resulting in a proposal for TOF using multi-gap resistive plate chambers (MRPC) for the ALICE experiment, submitted in late 1999. http://alice.web.cern.ch/Alice/TDR/alice_tof.ps The MRPC TOF project at ALICE is now underway with a budget of 17 M CHf. Members of the STAR TOF group participated in the CERN development work from 1997 to 2000. In 2000 and 2001, ALICE generously allowed STAR to share the test beam line at CERN for testing of prototype STAR TOF modules. These tests were successful, resulting in a proposal to STAR in April 2001 for the installation of a single tray (180 channels) of MRPC TOF, TOFr. http://mac8.rice.edu/~TOF/documents/tofr_prop.pdf This TOFr tray was tested for 70 days at the AGS in a high-radiation area in March to June 2002. Although the beam quality was poor (non-relativistic momentum spread), the tray performed exceptionally well and will be installed in STAR for the FY2003 run.

We have demonstrated that we can achieve sub-100 ps time resolution with this technology. In the current STAR detector, large acceptance PID is based on dE/dx information from the TPC and SVT. This allows kaon and pion identification out to ~0.6 GeV and proton identification out to ~1.0 GeV. A TOF system in STAR with <100 ps time resolution will extend the momentum reach of these measurements to >1.8 GeV and >3.0 GeV, respectively.

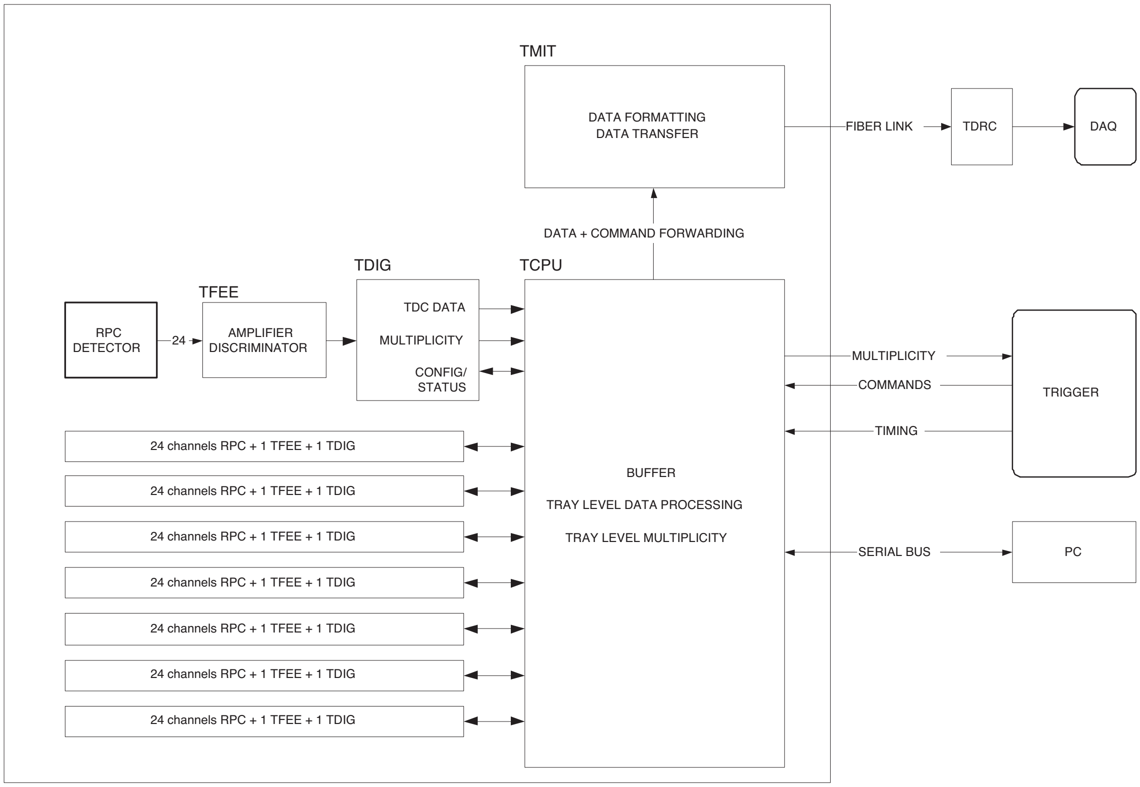
A proposal to build a large-area TOF system using MRPC technology was submitted to STAR in May 2002 and is currently under review by STAR. http://mac8.rice.edu/~TOF/TOF.pdf Reference 7 therein contains a list of published references of the research leading to this proposal.

Scope of Work:

The scope of this R&D proposal is the development of compact, fast, and inexpensive electronics for a large area TOF system. All beam tests of MRPC TOF modules to date as well as the TOFp and TOFr systems relied on CAMAC based TDCs requiring external "start" signals and consequent long cable runs to delay the "stop" signals. These systems generate excellent time resolution. However, in addition to the fact that these systems are slow and would have dead time in a fast-event-rate environment, cost and space considerations would prohibit integrating more than a few hundred channels into STAR. We propose developing and testing a clock-driven TDC based system with the necessary interfaces to test this system asynchronously with cosmic rays and test beams, and ultimately to test the system in synchronous mode in the STAR detector. The duration of the proposal will be for two years. The effort will be complemented by work under an SBIR grant.

Lloyd Bridges, an electrical engineer who operates his own business and who has participated in the design of TOF electronics with the STAR group since 2000, received a $100k SBIR grant beginning in August this year for nine months. The objective of this grant is to integrate the CERN HPTDC chip into an electronics card that will work in the STAR TOF system and other commercial applications. This will be equivalent to the development of a prototype TDIG card as described in the TOF proposal. For an overview of the proposed electronics design for STAR TOF, see Fig. TOF1.

STAR TOF: TOP LEVEL ELECTRONICS



There are a number of design issues to be investigated for the development of the front-end card TFEE. This card receives the differential signals from the MRPC, amplifies and discriminates the signal, and interfaces with the TDIG card. This card also serves as the interface from the gas enclosure and receives the twisted-pair signal cables from the MRPC. We are investigating methods of reducing the sensitivity to RF pickup, a source of time jitter. We have demonstrated that undesirable coupling between the amplifier and the gas box can increase jitter. The tendency is greatly reduced if the amplifier is mounted on a card that is an integral part of the gas box. We will need to test these ideas further with actual beams.

We are also investigating recently available amplification components. There are two new amplifiers available that are marginally improved over the current Maxim 3760 but are ~$3.50 less per channel. We also want to investigate the use of MMIC's (Monolithic Microwave ICs) that are intrinsically high impedance and might be a better match to the twisted pair signals from the MRPC modules. We also want to investigate the use of a new smaller, faster comparator that has recently become commercially available. It has the added advantage of built-in hysteresis and true PECL output.

We also need to complete a series of tests now underway to see the effect of different gas mixtures on the efficiency, dark current, noise rates, signal shapes, and ultimately the time resolution. All but the last test can be performed on the lab bench. These tests are very important since we have some indication from the test beam that we might be able to operate on a gas of just freon. This would be an enormous simplification of the detector system.

The MRPC signals are small (~50 fC) and fast and we have not been able to develop any adequate way of reproducing the signal with a test pulse. Sources produce real pulses but they are not strong enough to penetrate multiple detectors, required to make timing measurements. Therefore, in order to be able to adequately test the electronics with realistic pulses, and to account for coupling effects between the amplifier and the gas box, we plan to build a small gas box as a testing facility. This box could contain up to four, 6-channel MRPC modules and a 24-channel TFEE interface card. We would plan to use this small detector as a cosmic ray test facility and to transport it for testing at beams. This would allow a complete system test of the prototype TFEE and TDIG card with real MRPC signals. We would then be able to quote a number for the time resolution of a complete system using the CERN HPTDC chip.

There are a number of improvements to the MRPC module itself that we would like to investigate with the help of our Chinese collaborators in STAR. The ALICE group has reported that they can reduce the cross-talk between pads and improve the time resolution for particles at the pad boundary by increasing the surface resistivity of the electrodes by two orders of magnitude beyond what STAR is currently using. We should investigate these materials and see if we can get similar improvements. We should also investigate minor modifications to the mechanical structure of the modules that could facilitate ease of manufacturing and consistency of the resulting modules.

We also plan to begin the development of the remaining three electronics cards in the system: 1) the TCPU card which interfaces to the trigger and external clock, reads out the HPTDC chip on the TDIG card, and interfaces to the TMIT card which is the beginning of the fiber link to DAQ: 2) TMIT as just described; and 3) TDRC, the daq receiver card. The TCPU card will need to receive an external clock signal that is stable to 0.1 ns. These signals are now distributed in STAR by the TCD card. We plan to study the jitter in this external clock and determine the time dependence of the phase shifts in the distribution of this signal. We will investigate possible modifications to the TCD card so it can deliver clock signals suitable for TOF.

The STAR DAQ Upgrade R&D proposal includes the investigation of new, high-capacity low-power fiber links. The TMIT card or at least many of its elements will likely arise from that development effort.

We plan to investigate adapting the SMD receiver card to function as a TOF receiver, either on a temporary or permanent basis. The bandwidth and memory capacity need to be investigated, and the memory chips may require upgrading. It may require a new fiber interface as well. The FPGA will need to be reprogrammed to be TOF specific.

Year 1:

Deliverables:

We will produce a prototype amplifier/discriminator card and clock-driven TDC card. We will conduct a system test of the above with real MRPC TOF signals from cosmic rays and test beams. We will also test the latest generation of MRPC TOF modules

Personnel:

Physicist 75% FTE (provided from U. of Texas base)
Physicist 25% FTE (provided from U. of Texas base)
Physicist 50% FTE (provided from Rice U. base)
Physicist 50% FTE (provided from Rice U. base)
Postdoc 20% FTE (provided from Rice U. base
Electrical engineer 50% FTE (provided from SBIR)
Electrical engineer 100% FTE (provided with R&D funds)

Year 2:

Deliverables:

The electronics developed in year 1 will be adapted to function in a synchronous manner in the STAR detector environment. A clock distribution system with sufficient stability for high-precision TOF measurements will be demonstrated. A connection to DAQ will be demonstrated using the new optical links and supporting the high event rates of the DAQ upgrade. We will also conduct a full test of the system at a synchronous beam.

Personnel:

Physicist 75% FTE (provided from U. of Texas base)
Physicist 25% FTE (provided from U. of Texas base)
Physicist 50% FTE (provided from Rice U. base)
Physicist 50% FTE (provided from Rice U. base)
Postdoc 20% FTE (provided from Rice U. base
Electrical engineer 100% FTE (provided with R&D funds)

The Table below summarizes the anticipated costs for this R&D task:

Category	Description/comments	FY 2003 K$	FY 2004 K$	FY 2005 K$
Salaries (includes fringe)	Only for personnel supported from R&D funds	$64k	$68k	-0-
Travel	To test facilities and to visit ALICE at CERN	$12k	$12k	-0-
Purchases	Prototypes and test beam supplies	$14k	$15k	-0-
Overhead costs	Only for salaried personnel supported from R&D funds	$38k	$39k	-0-
Total		$128k	$134k	-0-

V. High Resolution Inner Vertex Detector Development for STAR

Principal Investigator: H. Wieman
Lead Electronic Engineer: Fred Bieser
Main Investigators:
S. Kleinfelder
H. Ritter
H. Matis
F. Retiere
E. Yamamoto
M. Oldenburg

We propose development of a new high resolution inner vertex detector for STAR which will open new dimensions in the study of heavy ion collisions at RHIC.

In elementary collisions, heavy quark production provides a benchmark process to study perturbative QCD. The heavy quark mass, m_Q, defines the scale at which the strong coupling constant, α_s, is evaluated. Since $m_Q \gg \Lambda_{QCD}$, the inclusive production properties should be calculable within perturbation theory. Furthermore, measuring the bottom quark yield as well would provide a better understanding of some non-perturbative processes. Indeed, due to their different masses ($m_c \approx 1.0 - 1.6$ GeV/c^2, $m_b \approx 4.1 - 4.5$ GeV/c^2), pQCD is probed at different Q^2, where the contributions of non-perturbative effects are different.

For this reason, heavy quark production (c,b) has drawn tremendous interest in the heavy ion community. Due to their large mass, c and b quarks are predominantly produced from the (pQCD-scale) interactions of initial state partons. Lighter quarks, however, may be produced throughout the evolution of a heavy ion collision. By this virtue, the absolute c and b yields provide a direct connection to the initial state. The process of hadronization of heavy quarks (manifestly non-perturbative), however, will depend on the dynamical evolution of the system.

	Mass (GeV/c^2)	$c\tau$ (μm)	Quark Content
D^0	1.865	124	c ubar
D^+	1.869	317	c dbar
D_s^+	1.969	140	c sbar
Λ_c	2.285	62	u d c
B^0	5.279	468	d bbar
B^+	5.279	462	u bbar

Table 1: Properties of several charmed and bottom particles

With the High Resolution Inner Vertex Detector, we will have the capability of making high precision measurements of charmed and bottom particles at STAR.

Since the majority of charm quarks produced will end up in open charm (D^0, D^0bar, D^+, D^- D_s^+, Table 1), measurement of D mesons is necessary to obtain an absolute yield for c-cbar production (N_{ccbar}). As the relative yields of charm hadrons could be significantly modified by the existence of a thermalized partonic state prior to freezeout, measuring the yield of the various charmed hadrons in p-p and heavy ion collisions may provide a signature that a new kind of matter is created in heavy ion collisions.

The ratio of the yield of J/ψ over open charm (e.g. D^0) also tests whether or not charmed quarks emerge into a thermalized system. The behavior of the J/ψ yield in heavy ion collisions is one of the most widely discussed means for probing the formation of a deconfined state of hot partonic matter. In general, it is more precise to study the yield with respect to the yield of open charm than with respect to the yield of related hard processes such as the Drell Yan spectrum that was used by the NA50 experiment at CERN SPS.

Models for collective expansion of a hot, thermalized medium indicate that transverse flow significantly increases the mean transverse momentum of charm hadrons. Transverse flow, as measured in experiments to date, is due to the multiple collisions between particles, but it is unclear whether flow arises from hadronic or partonic interactions. Measuring an increase of the charm hadron average transverse momentum from p-p to Au-Au collisions would provide evidence of the system collective expansion at the partonic level.

In addition, this detector may be used to tag heavy quark jets at high p_t, by distinguishing an electron from semi-leptonic decay of the heavy quark via its displacement from the primary vertex. The suppression of collinear radiation for heavy quarks is calculable in perturbative QCD, leading the “dead cone effect”, which influences the fragmentation and is predicted to reduce the energy loss of heavy quarks in dense matter in a way that is calculable in pQCD. This effect leads to an observable enhancement of the ratio of d-mesons or b-mesons to pions at sufficiently high p_t, and could be an extremely important tool for studying partonic energy loss in dense matter.

Extracting a high precision measurement of charm will require excellent background rejection. It is possible to reject background if one can utilize the lifetime of the charmed particles. With lifetimes measured in 100’s of microns, it is necessary to have a detector that can resolve a vertex displacement on the order of the lifetime.

The High Resolution Inner Vertex Detector will provide STAR with this capability. The detector will provide, for each charged particle that traverses its fiducial area, two high precision space points within 4 cm radially of the collision vertex. The proximity of the detector to the collision point is necessary to achieve the resolution required to reject background.

The short-lived particles will be measured by calculating the invariant mass from the decay particles. The number of events required to achieve a given level of statistics scales as $N \propto B/S^2$, where B is the background under the invariant mass peak and S is the signal in the peak. By aiding in the selection of tracks that do not point back to the primary vertex, the vertex detector limits the number of tracks contributing to the combinatorial background, B and has a dramatic effect on the amount of beam time required to achieve a given physics result. Our GEANT simulations (see Fig. 1) show that the combinatorial background, B, has a very strong dependence on the thickness of the first detector layer. We are proposing a 50 μm thick inner silicon layer plus aluminum Kapton cable located at a 2 cm radius from the beam plus a 1.8 cm radius[1] 600 μm thick Be beam pipe. The GEANT simulation shows that the combinatorial background for our design of 50 μm is 19 times smaller than using 300 μm of silicon, a thickness believed possible with the more conventional pixel designs using a hybrid approach. A factor of 19 reduction in required beam time is strong justification for developing the thinnest technology.

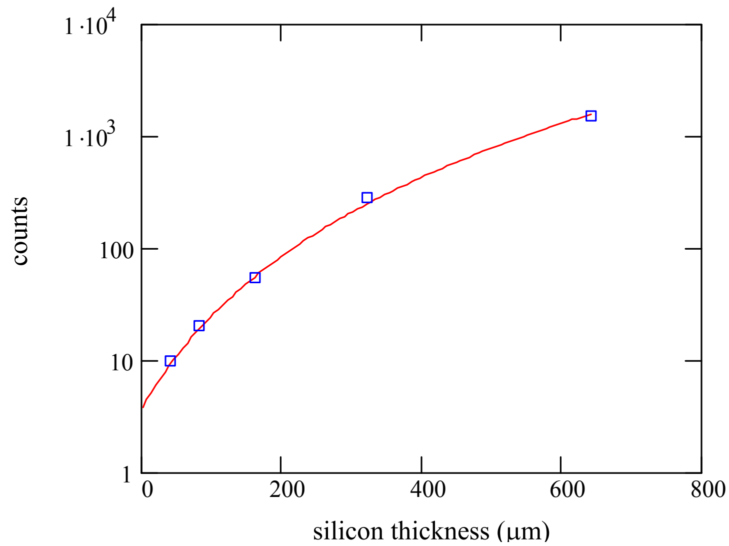


Figure 1: Combinatorial background from a GEANT calculation as a function specified detector silicon thickness. The simulation is for a 760 μm beam pipe with silicon layers at 2.8 cm and 3.8 cm. The curve guides the eye.

We have focused on an Active Pixel Sensor in CMOS approach for this vertex detector development, because like CCDs a detector can be built that utilizes a single layer of thinned silicon. The current APS technology is close to a realizable detector system, if all of the pixels are read out like a CCD. It has two main advantages over CCDs which are important for STAR. One it is more radiation hard than CCDs, and two it can be readout faster and with less power than CCDs. Another distinct advantage is the promising future of combining sophisticated electronics on the same chip as the detector. This has the potential for much faster readout speeds and low power if one can accomplish on chip zero suppression. Such a technology could be satisfactory at the highest predicted RHIC luminosities. Our initial approach, however, is to develop a simpler readout scheme with off chip data correction and zero suppression which can be used for a first generation APS detector in STAR. This will work with the anticipated RHIC luminosity of the next 10 years.

There are several items, both electronic and mechanical, to be addressed by this R&D program which are important preparation for the construction and use of the proposed high resolution vertex detector in STAR.

Already, several APS chips have been demonstrated to work with minimum ionizing signals. It is believed that further design and testing will result in better signal to noise performance which will improve the normal tradeoff of particle detection efficiency vs accidental rate. R&D work will be done to demonstrate that this technology can be successfully scaled from our small test chips to a full large area ladder design. A design constraint for the large system design is full detector readout in 20 ms. This speed is sufficient for the expected RHIC luminosity. Two approaches are under consideration for the large scale readout: analogue vs digital; either way requires development work. A differential analogue driver or an ADC will have to be developed as part of the APS chip design. An initial constraint for either design is that it adhere to a 100 mw/cm^2 power budget which is known to be within the cooling capabilities of forced air. We believe this can be done but it must be demonstrated in the R&D program.

The 20 ms readout time complicates the DAQ interface since a single APS detector read potentially contains information for several trigger events. Developing an approach for merging vertex data with the main STAR data stream is one of the projects for this R&D program.

Additional R&D effort will be devoted to on board data processing and sparsification. This is particularly important for a detector of this type where the total number of pixels, in excess of 90 million, is more than the TPC pixel count. The fraction of pixels with useful hit information is less than 1%, so the benefits of sparsification are significant.

The APS detector breaks new ground mechanically and requires R&D accordingly. To achieve the ultimate in thinness, we will explore construction methods based on thinned silicon and associated cables supported under tension with no additional backing or cooling material. We also will develop a mechanical design that allows rapid insertion and removal of the detector. As far as we know rapid insertion capability in the center of a large coaxial detector has not been attempted before, but we believe there are two reasons why this is a necessary requirement for operating at RHIC at such a small radius. The main reason is potential destruction by beam excursions. Since the area of silicon is relatively small for a vertex detector, detector destruction is not a major catastrophe if it can be rapidly replaced without significant loss of beam time. A second advantage of rapid retraction is the solution to the beam pipe bake out problem. R&D on the support structures will include controlling and measuring detector position. Extending forced air cooling capability while limiting structure vibration will also be explored. Progress in this direction will expand electronic options.

Mechanical R&D will be invested in the development of a small radius beam pipe which is integral to this detector. Currently STAR uses a 4 cm radius beryllium beam pipe which is a uniform cylinder construction that must support both vacuum and the gravitational load of an extended pipe. By exploring a design which separates these two mechanical functions we should be able to reduce the wall thickness in the region of the vertex detector and improve detector performance.

Our R&D program will require significant software effort for detector diagnostics, APS data reduction, integrated tracking for simulation within the STAR environment. To the extent possible this development will be done with goal of having components that can be used in a final installation of the detector into STAR.

The R&D of this program will focus on developing a detector for early implementation in STAR. While it is hoped that APS breakthroughs are made such as photo-gate development which allows rapid on chip zero suppression, the emphasis of the effort will be development of a detector that utilizes as much as possible the APS technology as it stands today.

The following summarizes deliverables for the 3 year R&D program. This is followed by a partial list of development items.

<u>Year 1:</u>

Deliverables

1. Physics driven requirements for the APS vertex detector.
2. Develop and evaluate APS designs appropriate for a first generation detector system.
3. Develop and evaluate mechanical concepts for support and cabling of thinned silicon ladders
4. Simulate performance in the STAR environment

Personnel

Senior Electrical Engineer	25 % FTE	provided from LBNL base
IC design Engineer	20 % FTE	supported by UCI
Senior Physicists	100 % FTE	from LBNL base + LDRD
Post-doc	100 % FTE	from LBNL base
Post-doc	50 % FTE	supported with R&D funds
Grad. Student	125 % FTE	supported Univ. Heidelberg +

		LBNL LDRD
Summer Under Grad	25 % FTE	LBNL LDRD
Mechanical Engineer	25 % FTE	from BNL base
Total personnel	4.7 FTE	

Travel, purchases and subcontracts

Travel	$10k
IC foundry	$30k
Subcontracts- for board assembly	$10k
Machine shop- for test structures	$30k
Purchases- misc. parts; test equip.	$10k
total non-personnel costs	$90k

Year 2:

Deliverables

1. Single APS with demonstrated required readout speed
2. Ladder module mechanical conceptual design
3. On board data reduction conceptual design
4. Beam pipe conceptual design

Personnel

Senior Electrical Engineer	30 % FTE	provided from LBNL base
IC design Engineer	20 % FTE	supported by UCI
Senior Physicists	100 % FTE	from LBNL base
Post-doc	50 % FTE	from LBNL base
Post-doc	100 % FTE	supported with R&D funds
Grad. Student	125 % FTE	supported Univ. Heidelberg + R&D funds
Summer Under Grad	25 % FTE	R&D funds
Mechanical Engineer	50 % FTE	R&D funds
Total personnel	5 FTE	

Travel, purchases and subcontracts

Travel	$10k
IC foundry	$30k
Subcontracts- for board assembly	$10k
Machine shop- support test structures	$20k
Purchases- misc. parts; test equip.	$10k
total non-personnel costs	$80k

Year 3:

Deliverables

1. Prototype APS ladder with readout and data reduction module
2. Prototype mechanical ladder module
3. Mechanical conceptual design for detector support and insertion
4. Conceptual design for alignment determination
5. Design document to support system proposal

Personnel

Senior Electrical Engineer	30 % FTE	provided from LBNL base
Electrical Engineer	50 % FTE	R&D funds
IC design Engineer	20 % FTE	supported by UCI
Senior Physicists	100 % FTE	from LBNL base
Post-doc	50 % FTE	from LBNL base
Post-doc	100 % FTE	supported with R&D funds
Grad. Student	125 % FTE	supported Univ. Heidelberg + R&D funds
Summer Under Grad	25 % FTE	R&D funds
Mechanical Engineer	50 % FTE	R&D funds
Total personnel	5.5 FTE	

Travel, purchases and subcontracts

Travel	$10k
IC foundry	$50k
Subcontracts- for board assembly	$10k
Machine shop- proto ladder module	$40k
Purchases- misc. parts; test equip.	$10k
total non-personnel costs	$120k

The Table below summarizes the anticipated costs for this R&D task:

Category	Description/comments	FY 2003 K$	FY 2004 K$	FY 2005 K$
Salaries (Includes fringe)	Only for personnel supported from R&D funds	$32.5k	$153.7k	223.2k
Travel	Pixel conferences and LEPSI/IReS visits	$10k	$10k	$10k
Purchases	See text above	$10k	$10k	$10k
Subcontracts	See text above	$60k	$60k	$100k
Overhead costs	Only for personnel supported from R&D funds	$20.8k	$102.8k	$151.8k
Total		$133.3k	$336.5k	$495k

The following is a partial list of projects and tasks to be addressed in the R&D program. Some have been started, others have not been addressed or planned. These items give some scope to the exercises outlined above.

Simulation:

Abbreviated simulations, quantify performance expectations.

Integrate vertex detector into STAR tracking

Simulate vertex detector performance in the STAR software environment

Electronic:

APS 0
1st copy of LEPSI/IReS CMOS APS. Single point readout – pixel connected to output buffer and non-buffered output with row and column selection via shift registers. 0.25 micron TSMC process through MOSIS. 4 variations – two with TX isolation. (DONE)

APS 1
2nd copy same as APS but with more FET size variations and each column has own current source. (DONE)

APS 2
A small part of a larger UCI chip. 0.5 micron technology

APS 3
An APS with focus on fast readout. Requires on chip ADC or analogue differential driver.

APS ladder 1
This will require a full wafer run. The ladder will consist of electrically isolated chips arranged in a row and cut from a single wafer.

Read out board 0
Small test board for reading out APS 0 and 1. Connects to LabVIEW on MAC. Used for first characterization of APS 0 and 1. Used for ALS Beam tests and radiation damage characterization. (DONE)

Read out board 1A
Next generation readout board with modern ADC, FPGA and memory. Designed for speed and development of readout approaches that could be used in STAR. Improvements for better multi-board integration to help in multi-chip telescope testing in the ALS electron beam.

Read out board 1B
Modified from 1A to provide a development platform for on board data filtering and data reduction involving cluster finding and reduction to hit locations.

Read out board 2
To readout a multi-APS ladder. This will serve as a prototype for the final STAR vertex readout system and will include capabilities developed in Read out board 1B.

DAQ Interface
Development work is required on determining how to interface the APS Vertex detector to the STAR DAQ system. The vertex system presents a special interface issue because this vertex detector will read out slower than other detectors and a vertex detector event will contain useful hit information associated with several trigger events. A development plan for this activity remains to be done.

<u>Mechanical:</u>

Support Structure 0
This device tests ability to mechanical couple to thin silicon and load it under tension and provides quantitative working load limits. (DONE)

Support Structure 1
Develops concepts for supporting thinned silicon under tension. Explores issues of mechanical stability, limits of air cooling velocity and induced silicon surface vibration.

Support Structure 2
Develops concepts for support of thinned silicon plus aluminum flex PC cable and investigates ability to use wire bond connections from the silicon to the cable.

Support Structure 3
Develops a concept for supporting a group of 3 ladders. 12 of these 3 ladder groups will form the two layer silicon structure.

Cooling test
Determine limits of ladder cooling by air flow either with mechanical test module or calculation.

Readout Support
Develops a concept for supporting the ladder groups and carries the off ladder readout electronics with water cooling. Includes insertion and retraction mechanics used for routine maintenance and removal for beam line bake out.

Aluminum Cable
Development of manufacturing methods for producing aluminum flex PC cable. Explores issues of pattern control and methods for making vias (electrical connections between layers)

Calibration and Alignment
Develop methods for high precision determination of detector silicon location.

Beam Pipe Design
A new small diameter beam pipe must be developed to accommodate the APS detector design. A concept is under consideration, but design work and prototyping remains to be done.

Software Development:

DAQ 0
A LabVIEW program for reading out and testing APS 0 and 1 has been developed. (DONE)

DAQ 1
Modified LabVIEW program to interface to Read Out Board 1A and 1B. Additional setup options and designed data output formatting.

DAQ 2
Program to readout a full multi APS ladder. Will operate with Read Out Board 2

Tracking Code 1
Diagnostic code for setting up ALS electron beam testing with multiple APS telescope. Capable of online track recognition to be used for telescope alignment.

Tracking Code 2
Integration of the APS vertex detector to STAR tracking. Used initially for simulation, but later will serve as a diagnostic tool in the STAR environment.

Pixel Monitor
Rapid specialized measure of hardware function. To be used initially with Read out board 2 with later use in the final STAR installation.

Footnote:

1. A smaller beam pipe of around 2 cm radius should not pose a problem for the RHIC beam. Private Communication Steve Peggs.

VI. Micropattern Readout Development for Gas Detectors for STAR

N. Smirnov, Yale University, Principal Investigator
R. Majka, Yale University
H. Wieman, LBNL

Abstract: A new detector concept is described consisting of a fast, compact Time Projection Chamber and a direct imaging Cherenkov detector that can be used for particle tracking and electron identification in relativistic heavy ion collisions. The TPC part of the detector utilizes a short drift region and fast drift, low diffusion gas to allow operation at high luminosities foreseen at RHIC. The Cherenkov part utilizes a large area CsI photocathode on the outer surface of the detector to image Cherenkov light produced by electrons. Both the TPC and Cherenkov parts employ micropattern detectors, such as Gas Electron Multipliers (GEMs) in their readout. The same detector technology can be used to construct fast, good space resolution, low mass Pad Detectors with low production and FEE cost.

The main reason for the anticipated RHIC upgrade to much higher luminosities is to allow for very careful and detailed studies of "special" and low cross section phenomena in Au+Au, p+A, p+p and e+A interactions.

Operating at luminosities of 40 times the RHIC design luminosity, the tracking detector should be capable of operating at high rate with high quality tracking (for both low and high momentum particles), with good particle identification (PID) and dedicated trigger power.

While the present STAR TPC is expected to perform well at luminosities up to four times the RHIC design value, STAR will have serious problems with this device as the main Tracker/PID detector when the luminosity reaches the planned ultimate value of 40 times the design value. The large drift distance is a principle limitation of the data rate capability and will lead to event pile-up. Positive ion build-up in the main drift volume will lead to distortions that will compromise the TPC's performance. The lack of space inside the STAR magnet leaves no room for additional new detectors to assist in tracking and PID.

Based on the knowledge gained at RHIC during its first years of operation and the progress with development and construction of micro-pattern gas detectors, we propose an intensive R&D project and to develop a detailed proposal for new STAR tracking/PID detectors.

We expect that the Magnet (possibly with higher field strength), EMC, SVT and ToF Detectors at STAR will be suitable for operation at higher luminosity, along with an upgraded STAR tracker to be constructed for high luminosity operation. The proposal is to replace the main STAR TPC with new tracking detectors that include:

- a high precision, low mass Vertex Detector (APS technology)
- 16 identical mini-TPC's with short drift distances, fast, low diffusion working gas, and GEM Detector readout with identical azimuthal and rapidity coverage as the current TPC.
- 3-4 additional Pad Detectors at larger radius (with micro-pattern technology) to provide sufficient resolution and triggering capability for high Pt particles.
- A first Pad Detector covered with CsI within the gas volume used by the mini-TPC modules (with no windows) that will provide a powerful Cherenkov Detector for e+/- identification starting from momenta as low as 0.05 GeV/c (limited by tracking).

Detailed, full-scale simulation and reconstruction software has been developed to study the performance of the proposed STAR setup, and results have been presented and discussed.

The proposed new STAR setup will allow:

- continuing all directions of the present STAR Physics program with a focus on the capabilities to pursue the most interesting and new ideas, mostly associated with low cross sections or and/or large momentum.
- improved speed of data taking, PID and triggering
- allow more space for new detectors to be installed (aerogel Cherenkov detector, TRD, forward tracking, ….)
- high quality J/Ψ and Υ (both e+e- and μ+μ- decay channels) and "open charm" (D-mesons) measurements
- flexible detector setup that may be modified for different physics goals
- high quality measurements at both low and high Pt, including low momentum e+/- identification
- the possibility to increase the magnetic field for "small R"
- an "on-line track-finding/reconstruction" algorithm using data from Pad Detectors as "pointers" for mini-TPC's and independent / parallel computing for all 16 modules (as a first step)
- the possibility to test and calibrate all detectors before they are installed (including ExB, "space charge," alignment effects for the mini-TPC's, even though they are expected to be significantly smaller than in the current STAR TPC)

R&D has been started to prepare the proposal for future STAR collaboration decisions. We note the R&D necessary for this program has significant overlap with PHENIX plans for adding a TPC and Hadron Blind Detector. The intent is to coordinate these efforts and share development where appropriate.

During the next three years we would like to intensify these R&D activities to resolve the following issues:

1. TPC

- study and select the best "working" gas for the mini-TPC with GEM readout and with Cherenkov detectors in the same gas volume
- optimize pad structure for the TPC readout and Pad Detectors
- find a "reasonable" solution (performance – cost) for the FEE and DAQ
- construct a full-scale mini-TPC prototype and study carefully the operating parameters and construction approaches

For the TPC , it will be necessary to achieve a hit reconstruction and spatial resolution of ~ 200-300 μm both at the readout plane (azimuthal) and along the drift direction with the minimum number of read-out channels. In addition, good gain uniformity and stability are required in order to reach optimum spatial and dE/dx resolution.
The field cage and TPC + Pad Detector design, ion feedback and space-charge effects, gas purity, UV light transparency and scintillation, long-term stability and radiation damage all should be carefully studied. The special TPC Drift Cell is already under construction, and to begin these studies we shall use existing FEE and DAQ systems, R/A sources, lasers, cosmic-ray and test beam facilities.
For a test of the "full scale" TPC prototype (and detector) we will need a new, dedicated design for the FEE and DAQ systems. The Instrumentation Division (BNL) has started this job together with experts from PHENIX and STAR.

2. Micro-pattern Detectors

- develop micro-pattern detector mass production techniques, and study the possibilities of the utilization of these of detectors for different applications

GEM Detector technology is a very good candidate for the construction of high resolution, fast, low-mass Pad Detectors that can be used not only for TPC read-out or as high Pt trackers with good trigger performance, but for several applications in science and industry. The low production and construction cost together with (we hope) simple FEE are very attractive. The total area of GEM foils for the upgrades outlined above (including the outer pad detectors for long lever arm on high momentum tracks) could be 1000 m^2. This requires that a reliable, high-quality source of mass production foils must be located, and a dedicated test & construction facility should be organized.

3. STAR tracking improvement in the short term.

- study the possibility for early construction and installation of an additional, fast tracking detector in front of the present STAR TPC.
- a high space-resolution, fast tracking detector in a front of EEMC.

There is an interest in STAR to make use of the GEM technology to develop a thin, low mass, fast tracker to fit between the existing TPC and the silicon vertex tracker (SVT) in STAR on a shorter time-scale. This would improve the quality of tracking and reconstruction of the present TPC and aid in TPC-SVT track-matching. Additionally, thin tracking layers immediately inside the STAR solenoid poletips, covering $1 < |\eta| < 2$ would help tracking and momentum resolution in the region where the existing TPC has decreasing acceptance.

4. Cherenkov Detector.

- study different variants of pad detectors covered with CsI as a fast UV and minimum ionizing particle PID / tracking Detector

In STAR we have experience with the construction and utilization of Pad Detectors covered with CsI, and we will continue work in a joint effort with a group from Jefferson Lab. However it is extremely interesting to check the possibility to use multi-GEM foils with CsI on the "top" foil as a UV light Detector. To gain experience and allow the possibility of using this technology in STAR, we would like to collaborate and help with this R&D.

5. Mechanical design, installation, infrastructure, alignment, calibration, etc..

- We think that these questions are for the future R&D steps

6. Software

- continue "full scale" simulation / reconstruction software activities.

Milestones and Budget

FY03

- Complete TPC drift cell (including read-out plane)
- Gas studies with TPC, HBD
- Photocathode studies with CsI
- Design TPC field cage, Pad Detector and HBD pad structure
- Begin engineering design study of TPC/HBD detector system
- Begin design of HBD & TPC readout electronics
- Check different variants of GEM foils production in US industry

FY04

- Build and test TPC/HBD prototype detector
- Continue engineering design of TPC/HBD detector system
- Organize dedicated laboratory to test and construct pad detectors on the basis of GEM technology.

FY05

- Complete TPC detector design
- Complete design of TPC readout electronics
- Test mass production GEM Detectors

Micropattern Readout Development for Gas Detectors for STAR

Estimated Budget

Category	Description/comments	FY 2003 K$	FY 2004 K$	FY 2005 K$
Salaries (Includes fringe)	Mech. Technician (0.5 FTE)	45	45	45
Travel		10	10	10
Purchases	Laboratory equip., Test equip., electronics, radioactive sources, construction materials	100	150	150
Subcontracts	GEM foil production	20	100	100
Overhead costs		35	42	42
Total		**210**	**347**	**347**