0.1 Comments on the technical realization of the inner silicon system

0.1.1 Mechanical support structure

The support structure of the inner silicon tracker should be both mechanically stable and low mass. The amount of material in this structure will for a big part determine how its performance will be affected by not desired processes like multiple scattering, conversions, delta rays and nuclear interactions. On the other hand it has to provide a mechanically and thermally stable support for the detector elements. To make it possible to do maintainance and to accomodate a possible staged installation schedule, the structure also has to be highly modular.

It is foreseen that this support structure will have to support the 3 barrel layers of the inner silicon tracker, the 3 rings of the forward silicon tracker and that it will provide some kind of high accuracy mechanical connection with the active pixel detector. In case that is decided to use the existing silicon strip barrel to provide space points closer to the TPC, then the new support structure should also be able to accommodate the silicon strip ladders. However, it should be kept in mind that the stiffness and accuracy of the structure will benefit from keeping its dimensions small.

The mechanical support structure should be made with an overall accuracy of $100\mu m$, which is kind of the best accuracy which can be achieved for mechanical structures of this size. This overall accuracy will be sufficient to assemble the different parts of the system. Trying to improve on this accuracy would immediately drive up the cost. Locally the structure will have to be more accurate than $100\mu m$. For instance, the mounting surfaces of the sensor modules will have to be flat to within $50\mu m$ to avoid stress, and possibly breakage, of the ceramic hybrids.

The structure should also be thermally sound. It is not foreseen that the detector will be operated other than at room temperature, both during lab testing and while installed in STAR. However, there is always the chance of thermal excursions and the structure should be able to handle those. Preferably the thermal expansion coefficient should be zero. Where this can not be achieved, there should be enough slack to take up the expansion to avoid putting stress on components. For instance, sensor ladders can be mounted only rigidly on one side while the other side is seated in saphire mounts which make longitudinal expansion possible. Also special care should being taken in the choice of adhesives and avoiding 'bimetal' effects during construction of the parts.

A structure constructed out of carbon fiber composites currently seems the most promising. Many groups are using this material to build highly accurate trackers, so there is enough accumulated experience that we can rely on when designing and building such a complex structure. However, we should keep an open mind to techniques used in the industry (fro instance, injection moulding) which make mass production of small accurate parts possible.

0.1.2 Radiation levels

0.1.3 Silicon sensors

The most conservative choice for the sensors would be to use silicon strip sensors. The manufacturing techniques for these type of sensors are well established and are mastered by several manufacturers. Silicon strips have been and remain the first choice for most high energy experiment trackers.

The preference is to produce single sided devices with p^{+}implants on n-bulk silicon and polysilicon biased. They are relativily easy to produce with high yields and can also be handled without much difficulty in a standard semi-conductor lab. In contrast, double-sided devices have lower yields (so more expensive) and need special equipment to handle them.

To achieve sufficient resolution in two directions with single sided silicon strip sensors it is neccesary to use a stereo pair. This is accomplished by mounting two silicon strip sensors closely back-to-back with one of them having its strips at a certain angle with respect to the other sensor. However, usually the readout chips should be located at the same position for both sensors of the stereo pair. The main advantage is that the same hybrid can be used for both sensors which leads to a simple mounting construction. One way of making a stereo pair is to have a very small stereo angle. Two solutions are possible; using the same sensors and mechanically mount one of them at a small angle or manufacturing one of the sensors with its strips at a small angle. In both cases the chips can be mounted in the same place as the ones on the sensor with straight strips. Unfortunately, also in both cases, this will result in areas that are not active, so called dead areas. In the case of the sensor with the angle build in this can be solved by feeding out the signals with signal traces over the surface of the sensor to the location of the readout chips. This leads to a double metal design which is more complicated to produce, but this is a process which seems to be very much under control by several manufacturers.

A double metal design has the advantage that the strips can be placed at any stereo angle. The highest spatial resolution can be achieved by having a 90 degree stereo angle. Unfortunately this results in one strip crossing all strips in the other sensor of the stereo pair, which will increase the number of ambiguous hits. A small stereo angle will results in less ambiguity, but at the cost of having a (much) worse resolution in the direction parallel to the beam axis. For instance, a 9 degree stereo angle will result in a $800\mu m$ resolution along the beam axis when using $50\mu m$ strip widths.

Currently studies are underway to determine the occupancies and ambiguities in the proposed silicon tracker designs.

0.1.4 Cooling system

The envisioned inner tracking system will dissipate about 1 Watt per sensor assuming 5 APV25-S2 readout chips per sensor. To keep the thermal noise of the sensors low they need to be thermally decoupled from the hybrids which carry the readout chips. One way of doing this is to use glass transition pieces between sensors and hybrids. Still, the generated heat has to be carried away to avoid a temperature increase in the whole system. The foreseen Aluminum Nitride hybrids and thermal plates will transport the heat to an attached cooling pipe.

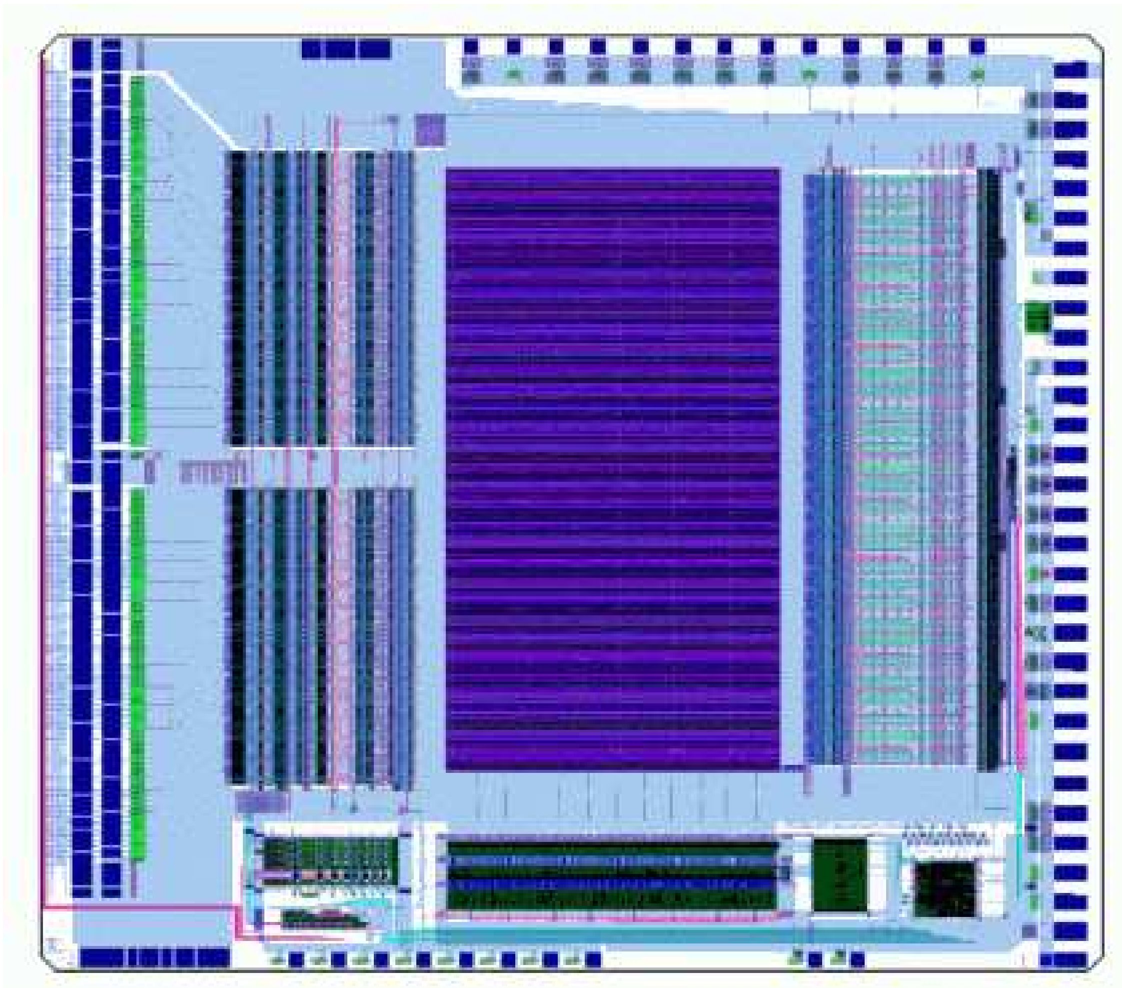
Since the radiation levels are not an issue the system can be kept at room temperature, this avoids problems with condensation and makes maintainance of the system much less complicated. In this case a simple underpressure water cooling will be sufficient. The big advantage of an underpressure system is that small leaks will not result in spillage of water inside of the detector system. Precautions need to be taken to avoid algea from growing in the cooling water. Avoiding light reaching the cooling water and an annual flushing with a chlorine solution is probably sufficient. A more sophisticated solution is to ozonize the cooling water through exposure with ultraviolet light. Adding algea inhibiting additives to the water should be avoided since it is difficult to predict their interactions with all the different materials in the cooling system.

Considering the planned size of the inner tracking system there is a good chance that the PHOBOS silicon cooling system can be copied without a problem. What needs to be investigated is, assuming that PHOBOS will have stopped operations when the STAR inner silicon tracker becomes operational, to take over the PHOBOS system as is.

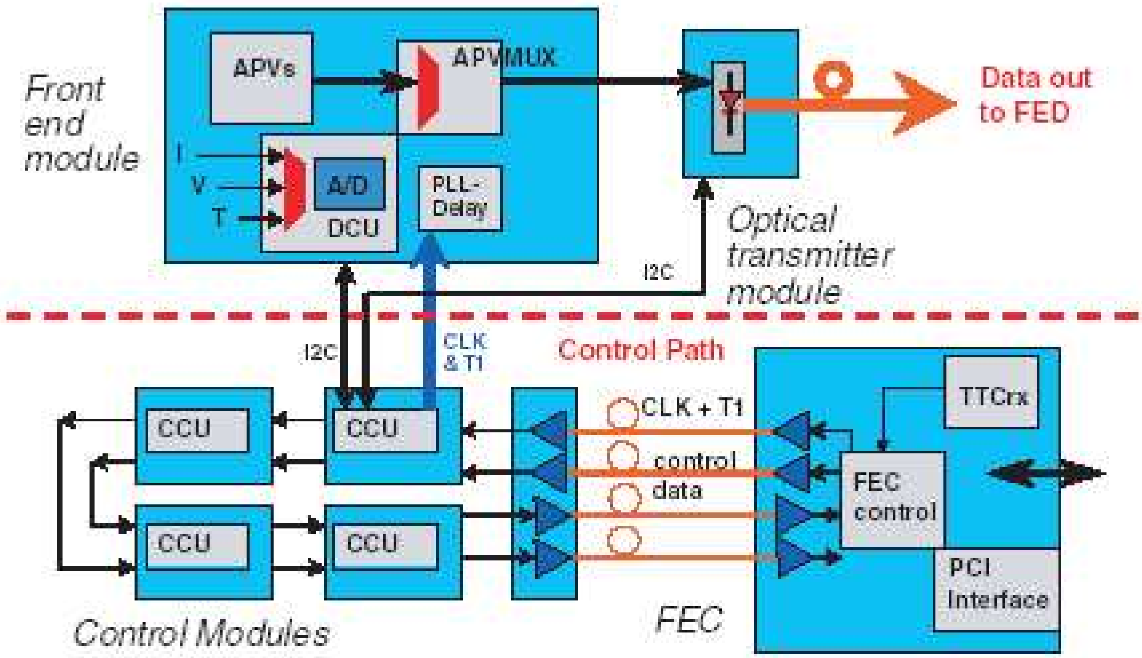
0.1.5 Front-end electronics

The current best estimate is that there will be about 1000 sensors in the inner silicon tracker barrel. With a strip pitch of $50\mu m$ this results in 640,000 channels that need to be read out. Designing and producing specialized readout chips for this system is not feasible because of the lack of time and manpower. For the sake of expedience it was decided to try to find a readout chip which was already being used for similar purposes by other experiments.

The best candidate so far is the APV25-S1 readout chip which was designed for the CMS silicon tracker and of which about 75,000 will be used. Each channel of the APV25-S1 chip consists of a charge sensitive amplifier whose output signal is sampled at 40MHz (which is the LHC rate). The samples are stored in a $4\mu s$ deep analogue pipeline. Following a trigger the data in the pipeline can be processed by an analoque circuit, mainly deconvoluting the amplifier response from the actual signal and associating the signal with a certain interaction (or rather beam crossing at LHC). The resulting analogue data can then be multiplexed and send to the digitizers. Although the analogue data leads to higher data volumes in the front-ends, it as the big advantage that charge sharing between strips and common mode noise can be studied in detail, which will greatly improve the understanding (i.e. performance) of the detector. The Equivalent Noise Charge (ENC) of the APV25-S1 depends on the capacitance of the strips and the deconvolution algorithm used, but, for our purposes, will be better than 2000 electrons. With $300\mu m$ thick silicon sensors this will give a signal-to-noise ratio of better than 11:1 when we take the most probably energy deposition by a Minimum Ionizing Particle (MIP). The power consumption of the APV25-S1 is about 2 mW/channel, i.e. about 0.25 Watt/chip. The chips are fabricated in the radiation hard deep sub-micron ($0.25\mu m$) process. Below is a picture of the 8055 x 7100 square micron APV25-S1 chip.



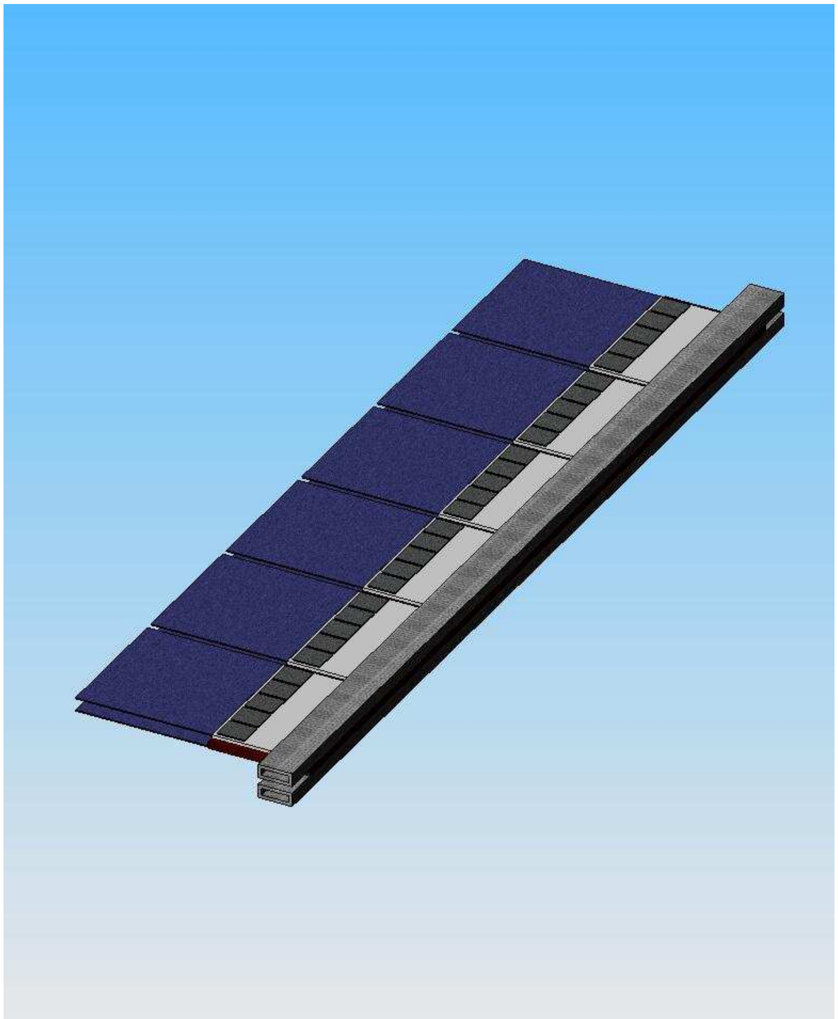
How the APV25-S1 chips are going to be read out remains to be decided still. In principle the CMS readout system with analogue optical links could be adopted, see below:



However, since the STAR radiation environment will be less harsh than that of CMS, it could well be that the front-end digitizers can be much closer to the detector and that there is no need for 100 meter long analogue optical links. The preference is that the readout system of the silicon system will be, for a big part, the same as for that of the GEM system, which is also utilizing the APV25-S1 readout chip. Considering the about 640,000 analogue channels that need to be digitized there definitely will be a need for some kind of zero suppression system.

0.1.6 Hybrids and cables

It is foreseen to use Aluminum Nitride K170 for the hybrids because of its excellent thermal and mechanical properties. The thermal conductivity of AlN is 170 W/m-K, which is about 6 times better than standard Alumina. Beryllia Oxide is about 1.5 times better than AlN, but, because of its toxicity, is very difficult to obtain, i.e. is much more expensive. One module will consists of several modules mounted on a common thermal plate, which also will be made of AlN. A ladder will then be build up out of modules mounted on a, preferably, carbon fiber cooling tube. Here is a, very preliminary, artists impression of a inner silicon tracker ladder:



Each module will have one low mass readout and control cable. These cables will need some R&D to find a proper balance between a low material budget and electrical requirements.

0.1.7 DAQ system

0.1.8 High-voltage and low-voltage system

Considering the quite standard requirements both the high voltage and the low voltage system can, most likely, obtained as almost off the shelf components. Since these systems will be located relativily close to the detector there is the need for remote control and monitoring. Companies like Wiener can build these systems to the desired specifications, including a CANBUS interface.

0.1.9 Alignment system

The final aligment of the inner silicon tracker will have to be done by tracks. Usually this is done through an itterative residual method. For this method to work the positions of the strips will have to be known with an accuracy comparable to their width, i.e. $50\mu m$, which is going to be very challenging.

Finding the position of each detector element on a ladder is relativily straightforward. An optical surveying system, which is available at MIT, makes it possible to do this with an accuracy of about $10\mu m$ in the plane of the sensors and about $50\mu m$ to $100\mu m$ perpendicular to the plane of the sensors.

While the ladders are being assembled into barrel layers the next survey step has to be taken. It is very unlikely that the MIT optical surveying station will be able the size of the assembled barrel layers. Logistically it is preferable that the barrel assembly takes place at BNL to avoid having to ship this rather vulnerable structure from another place to BNL. Unfortunately this means that something like a touch probe surveying station needs to be found at BNL. Such a system should be able to determine the ladder positions within the inner barrel structure with an accuracy of $50\mu m$ or better. The assembly will then have to take place in 3 stages. First the inner most layer will have to be put together and then surveyed. Then the same needs to be done for the second and then the third layer.

Hopefully the whole structure will be stiff enough to retain the surveyed positions after installation in the STAR magnet. A system with very accurate positioning pins and surfaces will be needed to position the whole system with respect to the pixel detector.

If there is not enough confidence about the position integrity of the system during operation, then there will be the need for continuous position monitoring. The only system which seems suitable for such a task is the RASNIK system developed at NIKHEF in The Netherlands. This system makes smart use of laser beams going through special masking structures to induce signals in photodetectors which are dependent on the relative positions of lasers, masks and photodetectors. At the moment it is not clear yet what the accuracy of this system currently is.

0.1.10 Slow control systems

A slow controls system has to measure all the working parameters of the inner silicon tracker. The temperature of the hybrids and the currents and voltages of the components on the hybrids need to be monitored continuously. Also cooling water temperatures, water flow rates and dry air flow rates need to be recorded regulary. Preferably all these monitoring values get enetered into a database. In case that the parameters get out of predefined operating values alarms should be send to the shift crew.

Although STAR is using EPICS as its standard slow control system there is a slight preference to use LabView instead. Labview provides the user with virtually any instrument driver and a very convenient user interface. LabView runs on both Windows and Linux. It is relativily simple to interface LabView and EPICS. However, at the moment, both options are still open.

0.1.11 Installation procedures