Report of the STAR Tracking Review Committee

June 8, 2000

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1 Executive Summary

We present here the Executive Summary of the report of the STAR Tracking Review Committee. The review was initiated on March 29, 1999 by the STAR Computing Project Leader and the STAR spokesman with the following mandate:

1. *To evaluate the state of the STAR software for tracking in the time projection chamber and the global reconstruction. The software packages associated with cluster finding, track finding, vertex finding, and TPC detector response simulation shall be included in the review. The evaluation should include among other things general performance, tracking efficiencies, details of the types of tracking inefficiencies, particle identification capabilities.*
2. *To evaluate, as above, present codes and plans for tracking near mid-rapidity in STAR using the SDD and SSD.*
3. *To determine the capabilities and plans for extending tracks found in the TPC to other STAR detectors (SDD, SSD, EMC, RICH) and to evaluate the efficiencies for tracking and particle identification.*
4. *To identify tracking issues for the present tracking codes that can be addressed in the short term (<6 months) both for the TPC alone and for tracking in/to other STAR detectors.*
5. *To identify tracking issues with the TPC and other STAR detectors not addressable with present codes in the short term but requiring longer term (6-12 month) upgrades or development. In this context the committee may wish to suggest approaches and directions for such development. Such suggestions are welcome, but the review is not intended as a forum for general discussion of tracking scenarios.*

The review report will be advisory to the Computing and Software Leader and the Spokesman.

The information presented here is a summary derived from a 20-page report prepared by the committee. Readers wishing to understand the full context of the various recommendations presented here are urged to review the full report.

1.1 Findings and Recommendation

In the report we discuss each of the issues below in some detail and offer recommendations for steps that would redress them. The major findings and recommendations are presented below.

1.1.1 Management Issues

While recognizing the most important progress which the tracking and reconstruction software workers have achieved we believe the managerial structure which has been in place has not been at a sufficient level.

- At the level of the STAR Council and Spokesman, offline reconstruction must be recognized as being of extreme importance to the success of the experiment. Indeed, it may warrant special attention because it does not have the same constituency structure as the detectors, and because of its cross-cutting and often invisible nature.
- The management also needs to evaluate the progress against clear milestones and it must be able to respond appropriately if the milestones are not met.
- The Reconstruction Project Leader should promote a clear vision for the evolution of tracking software within STAR and, together with the Computing Project Leader, should take the necessary formal steps to secure commitments from institutes to provide the required support.

1.1.2 TPC Related Issues

The TRS package is relatively mature, maintainable, and the level of realism achieved should be sufficient for the most common efficiency studies. However, the absence of TRS in the chain currently hampers the evaluation/testing of the clusterfinder and other components.

- The top action item, which the committee recommends should be taken immediately, is integration of TRS into the existing chain (BFC). Although further action items have been identified (see below) we feel that none of them are showstoppers.
- We recommend that the TRS developers work with the database team to incorporate the interface to the calibration database soon after integrating TRS into the BFC.
- The committee recommends that speed optimization of TRS be pursued at this point.
- We recommend to soon identify a person for TRS, who feels personally responsible for its maintenance, upgrades, and tuning.

Overall, the TFS package is an well-understood and much-exercised software tool. Its "reality level" is generally reasonable. One problem raises from the fact that the current clusterfinder does not provide reasonable uncertainty values while the current also supplies information on resolution directly to the tracking code. This violates the understanding of package purpose since the flow of information differs for TFS and TRS/raw data.

- The committee recommends to modify TFS such that it does not provide the resolution used to generate the individual hits but rather derive this quantity in the proceedings steps as is the case for TRS and raw data.

The performance of the overall event reconstruction in cosmic ray, laser, and RHIC beam-gas events, in addition to the earlier simulation studies on the unimproved code, provides some confidence that TCL and TPT are basically ready for year-1 data reconstruction and physics analysis using its output. The committee finds that some points still deserve attention:

- It appears clear that the time is right to perform hotspot checks on the clusterfinder (TCL), and do simple optimization.
- The committee recommends that more sophisticated use of currently existing STAR wide evaluation tools (in particular, the StMcEvent/StAssociationMaker) be developed for use with the clusterfinder.
- In light of the experiential fact that, without crossing angle information (available only at the track level), reliable position uncertainties cannot be obtained, the committee recommends *not* to invest effort in trying to calculate these uncertainties in the clusterfinder.
- The committee feels a top priority must be to generate hit-wise position uncertainties based on the local track parameters in all cases- i.e. even for the fast simulator.
- Instead of further evaluation the magnitude of the pattern recognition (root formation) bias, the committee recommends implementing the fix. It was stated that the route to elimination of this potential problem is understood, and a fix would take about 1 week's work.
- The solution to the above point involves a rapid estimate of the position of the primary vertex which we recommend to implement soon.
- The committee perceives that a rather small group of people is simultaneously *developing/maintaining* the tracker as well as *evaluating* it, and recommends that much more evaluation be done by STAR collaborators outside of this group.
- The committee recommends a careful evaluation of the distribution of the innermost padrow of the first correct hit on a track, to probe for potential problems.

In much of the evaluation discussed during the review, tracker evaluation centered largely on the correspondence between the reconstructed track, and the corresponding Monte Carlo track which was its best match according to the number of hits in common. In the terms used during the review, reconstructed/generated track pairs with the highest "qfact" were mostly considered. The committee worries that evaluations focussing on the largest-qfact matches may miss important information on ghosts and momentum resolution.

- We recommend that further evaluation efforts of tracks not center as exclusively on the largest-qfact.

1.1.3 SSD/SDD Related Issues

The committee was impressed by the very large efficiency and purity achieved by the SSD Hit Finder.

The SDD Fast Signal Generator is not yet in a state such that it could be included in the STAR reconstruction chain.

- An actual simulator of the digitized SDD signals is expressly needed to perform truly realistic simulations of the detector performance and, in particular, to optimize the cluster finder.

The committee recognizes that standalone track finding in the SVT based on a set of 3 or 4 points is clearly not very well constrained. Such a weak constraint can lead, in a standalone mode, to the reconstruction of a large number of ghost tracks. Track fits based on 3 or 4 points may not practically be amenable to more sophisticated treatments: standalone tracking and fitting, except for the lowest momentum of interest, does not appear a very viable long term strategy for STAR and SVT tracking. The results presented on SVT track to TPC track matching reflect the difficulty of the task and are no doubt the best indicator of the difficulty of the task at hand.

- The committee strongly recommends that a careful analysis be conducted to determine the inter-relation between the number of ghosts and the reconstruction efficiency for the SVT standalone tracker. The emphasis of this analysis should be on secondaries which constitute “la raison d’être” of the SVT.

The results on TPC track to SSD/SVT point matching were quite encouraging. On the onset, this tracking technique appears promising.

- We propose that the SVT group (including Nantes collaborators), while maintaining an optimization effort of the existing standalone tracker and matcher, should invest seriously in the development of a vector-to-point matcher in the spirit of the work presented by the Nantes group.
- Concerning the TPC track to SSD/SVT point matching we strongly recommend that the association of hits to the TPC tracks should make use of a tree structure: i.e. initially, SSD/SDD points should be allowed to be associated to more than one TPC tracks so one can evaluate which of the associations has the best quality rather than using, as in the analysis presented at the review, a “first tested gets the track” approach.
- Early passes in TPC track to SSD/SVT point matching procedure should include the main vertex i.e. one should try to associate SSD/SDD points which fall near/on an extrapolation of TPC tracks leading to the main vertex. We recommend that a Kalman filter approach would readily solve the problems involved in taking scattering into account.
- The matching algorithm should include the possibility to turn off a layer of the inner detector: i.e. on the onset, the tracker should be built to accommodate either a three-layer SVT, or an SVT+SDD four layer detector.

1.1.4 Global Reconstruction

The committee sees all tasks concerning year-1 global reconstruction well addressed by the existing code but also recognizes that the group is seriously understaffed to achieve the goals for year-2. We fully agree with the view of the Reconstruction Project Leader that at least 2-3 more full time people are needed in the near future to accomplish the task. We also make the following recommendations:

- For global tracks we recommend to store position and tracking parameters at the first *and* the last point in the TPC (using the Kalman fitter). We also propose to perform the extrapolation of global tracks to the non-tracking detectors (RICH, EMC, TOF) already during the ‘global’ reconstruction and store the momentum vector, position and error at the intersection together with the tracks.
- Regarding the Kalman fitter program for global tracks, the actual improvements on the physics have to be better documented.
- Work on the Kalman fitter should include the primary vertex and thus requires a material propagator program (e.g. GEANE) that allows the inclusion of effects based on the IFC, gas, and beam pipe material.

The primary vertex finding program (EVR) seems to perform well, but it seems to also cause some problems during the running of the BFC. Presently the improvements in the primary vertex resolution from year-1 to year-2 are only a factor 2, which is in contradiction to the vastly increased impact parameter resolution when including the SVT.

- We recommend to re-write the EVR code and make it more stable.

1.1.5 Future Planning

We recognize the short-term plans presented by the Project Leader as reasonable, especially since the address many problems that are also part of our findings.
In general the committee welcomes the long-range plans as presented, although it feels that the detail of information available is not sufficient to fully understand its implications. This is in part due the fact that the reconstruction group itself is still reflecting on these issues and that it has not yet finalize their detailed plans.

- The Reconstruction Project Leader should officially form an R&D group which aims at developing an improved and coherent tracking approach incorporating all tracking detectors. The *scope* of the effort should be well documented and a set of milestones should be defined precisely. All efforts have to be balanced vs. the need to maintain and, where possible, improve the current implemented tracking software, i.e. any new R&D efforts should not jeopardize current accomplishments.

2 Table Of Content

3 Introduction

In this report we present an assessment of the state of readiness of STAR offline tracking software and propose recommendations for short and long term planning. The STAR Tracking Review was initiated on March 29, 1999 by the STAR Computing Project Leader and the STAR spokesman with the following mandate:

6. *To evaluate the state of the STAR software for tracking in the time projection chamber and the global reconstruction. The software packages associated with cluster finding, track finding, vertex finding, and TPC detector response simulation shall be included in the review. The evaluation should include among other things general performance, tracking efficiencies, details of the types of tracking inefficiencies, particle identification capabilities.*
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9. *To identify tracking issues for the present tracking codes that can be addressed in the short term (<6 months) both for the TPC alone and for tracking in/to other STAR detectors.*
10. *To identify tracking issues with the TPC and other STAR detectors not addressable with present codes in the short term but requiring longer term (6-12 month) upgrades or development. In this context the committee may wish to suggest approaches and directions for such development. Such suggestions are welcome, but the review is not intended as a forum for general discussion of tracking scenarios.*

The review report will be advisory to the Computing and Software Leader and the Spokesman.

Information relevant to the work of the Committee was derived from the review meeting itself held May 4-5 at LBNL, from information compiled by the Reconstruction Project Leader for the review, from the referring project web sites, from interviews with numerous members of the collaboration, and from many interactions with the computing projects and subprojects leaders.
The committee membership was derived principally from the STAR collaboration, but the committee greatly benefited from having one member from the BaBar experiment at SLAC and one from the ALICE experiment at CERN.

In just a few weeks from now STAR will be faced with the first ‘real’ events which deploy track multiplicities never recorded before. It is a good time to review the readiness of the tracking software to meet the needs of the year-one STAR physics program, and to assess the ongoing development and upgrade program to ready the software for year two physics. As expressed in the charge above the review focussed on the status and plans for the software relative to year one and year two physics needs.

In this report we present the analysis of 5 major issues related to the state of tracking in STAR: Organization (Sec. 4), TPC tracking (Sec. 5), SVT tracking (Sec. 6), global tracking (Sec. 7), and future planning (Sec. 8). In covering these topics we believe we have spanned all of the issues raised in the charge.
This report covers the state of STAR tracking software from spring 2000. Changes in a variety of areas were underway throughout the review and we have tried to accommodate our conclusions accordingly.

The wide ranging nature of our recommendations is not intended to be a refutation of the many dedicated individuals who have worked tirelessly on STAR tracking software up until now. Indeed, the committee recognizes that without their previous efforts, many of the current recommendations for advancement would not even be available for us to consider.

It is the expectation that for each recommendation offered by the committee and accepted by the management a follow-up mechanism will be established. We are all aware of how difficult it is to keep certain issues at the forefront of attention in a situation where new challenges are being presented every day. We want to respectfully note, however, that many of the points we raise in our recommendations are critical to the success of the experiment and should be carefully monitored.

4 Organization of Project

The unique strength of the STAR detector is its ability to track all (or nearly all) of the charged particles within its large acceptance. The charged particle tracking is key to all of the STAR physics goals, including those that use the ancillary detectors such as the SVT or the EMC. Indeed, the TPC alone permits very interesting physics studies while the ancillary detectors without TPC tracking are at best, marginally useful. Thus the track reconstruction software is central to the role of the STAR detector and must be viewed as a "mission enabling" component of the detector. The level of effort and the managerial effort needed to insure its success must be provided by the collaboration.

At the level of the STAR Council and Spokesman, offline reconstruction must be recognized as being of extreme importance to the success of the experiment. Indeed, it may warrant special attention because it does not have the same constituency structure as the detectors, and because of its crosscutting and often invisible nature.

The software effort is complex and challenging. No other detector has up till now faced a tracking problem of the size and scope of that presented by STAR. Successful progress clearly requires a number of talented scientists working in a coherent and effective manner. The effort needs a clear management structure with the ability to efficiently integrate a number of different scientists (likely not all at the same location), to set realistic and adequate goals for near term (e.g. year one), mid term, and longer term reconstruction software. The management needs to structure the effort on the different time scales in the best manner. For example the longer-term effort might involve a tracking research and development group, etc. The management also needs to evaluate the progress against *clear milestones* and it must be able to respond appropriately if the milestones are not met. The software management must be concerned, of course, not just with the creation of the software but with its *maintenance* and *evolution* as well. While recognizing the most important progress which the tracking and reconstruction software workers have achieved - indeed, future efforts will surely build upon these - we believe the managerial structure which has been in place has not been at the level described above.

The Reconstruction Project Leader should promote a clear vision for the evolution of tracking software within STAR and, together with the Computing Project Leader, should take the necessary formal steps to secure commitments from institutes to provide the required support. Members of the collaboration themselves must appreciate the very complex nature of offline reconstruction tasks in general and more of us must be willing to commit useful blocks of time to work on significant detector-related computing projects.

5 Tracking in Main TPC

The committee acknowledges the excellent progress made by the TPC software group in the development of TPC tracking software. The committee recognizes in particular the outstanding efforts of Iwona Sakrejda in the coordination and implementation of tracking software.

In the following, we group discussion according to the software packages which perform the basic functionality of track simulation and reconstruction. For each package, we give a brief generic description of what the package should do. We do not summarize the presentations themselves, which naturally contain much more detail about the existing implementations.

5.1 TPC Slow Simulator

5.1.1 Committee's understanding of generic package purpose

The task of the TPC slow simulator is to interface with GEANT, which provides the energy deposited into the TPC gas by ionizing particles. This information is provided as a series of "hits," each with a position and amount of energy loss. From this information, the slow simulator generates the expected detector response, accounting for relevant physical processes in the gas determining the electron transport through the gating grid and to the proportional wires, electron avalanche on the wires and wire-to-pad coupling generating the analog signal, and analog and digital electronics response, including ASIC and DAQ logic. The end result should be data that is identical in format (compressed ADC-counts) and, ideally, in content, to what the DAQ would provide if the STAR TPC triggered on the event (in "real life") which was originally input into GEANT.

The simulator must account for a large number of complicated processes, each of which in principle can entail a detailed (and CPU-hungry) calculation. Generating reasonable statistics while treating each effect to the fullest extent of our knowledge would easily overwhelm any computing facility, rendering the simulation tool useless. Usually, a faster parameterization of a process can be used, which is "almost as good." Care must be taken to judge the overall effects of such simplifications, playing off CPU performance against depth of detail. Ideally, the compromise should be adjustable.

Although in principle not representing a distinct functionality for this software package itself, it is worthwhile to bear in mind that, as real data becomes available, it is foreseen that the primary use of the slow simulator will be to simulate the pixel patterns corresponding to a small number of tracks, and then to merge these simulated signals with real data events, which (of course) contain realistic noise and contamination. Likely the most reliable estimates of STAR efficiency will result from these so-called embedding studies.

When STAR event reconstruction code operates on raw data, it performs corrections (e.g. for gain variations), based on calibration factors stored in a database. Since, ideally, the reconstruction code should not "know" whether it is operating on real or simulated data, a further requirement is that the slow simulator should access the database and perform so-called "inverse corrections." This requirement is perhaps most important when one is performing embedding studies.

5.1.2 Review of existing implementation - TRS

Although the youngest software effort of the ones reviewed in this section, the TRS package is relatively mature, maintainable, and overall appears to be in good shape with regards to the description outlined above.

The level of realism achieved should be sufficient for the most common efficiency studies, and is on a roughly comparable level with slow simulators from existing/publishing (EOS, E895, NA49) and future (ALICE) TPC heavy ion experiments.

- The top action item, which the committee recommends should be taken immediately, is simple inclusion (formal integration) into the existing chain (BFC) that is available and tested nightly.

This is the only way to identify problems and stimulate feedback/evaluation from users other than the developers. Furthermore, evaluation/testing of the clusterfinder (and to a lesser degree, the fast simulator) is currently hampered by the absence of TRS in the available chain.

Further action item issues have already been identified (see below), the committee feels that none of them are showstoppers, and in particular, that inclusion of TRS in the chain should *not* wait until they are resolved.

- Related to the above point is the issue of interfacing to the calibrations database. A real obstacle to evaluating the clusterfinder (see below) was caused by the reconstruction code correcting the "data" based on calibration constants from the database; the correct procedure would be for TRS to apply the inverse corrections based on the *same* constants from the same database. Integration of the database into STAR simulation/reconstruction software is a relatively recent development, but the handshaking is beginning to stabilize, for those packages currently in the standard release. The committee recommends that the TRS developers work with the database team to incorporate this interface soon after integrating TRS into the BFC.

- Also very high on the priority list is to identify a "loving owner" of TRS, who feels personally responsible for its maintenance, upgrades, and tuning. The people who have brought TRS this far have done excellent work, and this recommendation does not reflect poorly on them. It simply recognizes that there are other issues (other STAR projects, Ph.D. theses) that are pulling these people away from TRS.

  While STAR can limp along for the short term (1-2 months) with a group of several knowledgeable TRS folks who can provide a quick bug fix or easy upgrade, the committee sees the need for a single person who will become intimate with all its parts.

- It is the understanding of the committee that not all of the "hooks" for the inverse corrections (mentioned above) are implemented into TRS. So that, even if the individual gains were available (see below), some code is still required to make use of them. The committee recommends that the important inverse corrections be identified (some discussion centered on whether individual gain corrections were important in STAR), and the appropriate code implemented.

- As mentioned above, performance bears on the utility of this simulation tool. At the review, there were several estimates of the CPU time to process a standard density event on an RCAS node; many seemed to agree that 20 minutes/event/machine was more or less the current status. If nightly test production of 40 events would include TRS, then, this would imply 13 computing hours for TRS alone.

  Appropriately, speed optimization has not been the main priority in TRS until now, and recent analyses of the code suggest that significant gains can be achieved without huge amounts of rewriting. The committee recommends that efforts in this direction be pursued at this point.

5.2 TPC Fast Simulator

5.2.1 Committee's understanding of generic package purpose

As discussed above, the slow simulator is intended to mimic the behavior of the STAR TPC detector (including readout electronics and DAQ), so that the entire reconstruction chain (including calibration corrections and clusterfinding) may be exercised. On the other hand, the fast simulator is intended to mimic the integrated effect of the detector *plus* the clusterfinder. Therefore, while the input is again GEANT hits, the output in this case are reconstructed hits, in the same data structures as are filled by the clusterfinder.

While one might hope for similar realism at the level of the hits, it is recognized that the large performance boost in using the fast simulator derives from a more simplistic parameterization of the underlying processes. Hence, the fast simulator is intended more for high-statistics exercises of downstream software. Very detailed studies employing, for example, embedding techniques, are not foreseen.

Similar to the requirement discussed for the slow simulator above, the chain downstream should ideally not "know" whether it is starting from hits coming from (1) actual TPC + clusterfinder, (2) slow simulator + clusterfinder, or (3) fast simulator.

5.2.2 Review of existing implementation - TFS

Overall, the TFS package is a mature, well-understood, and much-exercised software tool. Almost every TPC-based result to date has used it. The "reality level" (concerning topics such as track splitting, particle identification (dE/dx) resolution) is generally reasonable.

Some items which the committee believes deserve attention follow.

- A main issue (which will be repeated later in the discussion on the tracker) is that TFS smears the GEANT-generated hits by some resolution, (which depends on crossing angles, etc), and then puts this resolution into the uncertainty field of the reconstructed hit table. In this way, the tracker can make "intelligent" outlier-rejection choices, and the chi-square value characterizing the goodness of a track fit can have some meaning.

  The problem with this is that the clusterfinder does *not* provide reasonable uncertainty values (this is discussed below). Thus, the current TFS behavior does not simulate correctly the action of the detector plus clusterfinder, and so violates the understanding of package purpose.

  In addition, under the operating mode discussed above, users of the tracking code come to depend on "knowing" whether the upstream software is TFS (in which case the uncertainties, and chi-squares, are dependable) or the clusterfinder (in which case they are not dependable). This violates another point in our understanding of the package purpose, and may hamper full exploration (via simulation) of tracking issues that will arise with "real" data.

- Flagging of merged hits: As a rough approximation of the effect of hit merging, TFS merges hits whenever the GEANT-generated hits are closer than some cutoff distance. This is reasonable. Since merged hits will have less reliable position information, and are unusable from the point of view of particle identification via dE/dx, TFS flags the hits which are merged, so that downstream software may treat them specially.

  One wonders the degree to which this simulates reality. Certainly, in some cases, the clusterfinder will be able to determine that hits have been merged, and so can flag the resultant hit(s). However, if tracks cross particularly close to each other, the clusterfinder will not have this information; in this case, TFS is passing on information only knowable to a simulator, violating the understanding of the purpose of the package above.

- Again concerning uncertainties, it is a bit surprising that the uncertainty in the drift direction does not depend on drift length in the simulation. Clearly, the dip angle dependence (which is accounted for) is the dominant effect, and for tracks originating at the TPC center, there is a strong (anti)correlation between drift length and dip angle. However, it was acknowledged during the review that a z-dependence should be implemented.

- It appeared odd that the position of the resultant (merged) hit was determined by a weighted mean of positions, in which the mean is the *width* of the hit. Naively, total area would seem more appropriate.

5.3 TPC Clusterfinder/Hitfinder

5.3.1 Committee's understanding of generic package purpose

The cluster- and hit-finding package (often referred to simply as "the clusterfinder") is the first non-calibration/correction package in the data reconstruction chain. It should interface with the TPC pixel data produced by the DAQ (or a simulation of DAQ) and find the positions at which charged tracks cross the TPC padrows. Generically, this is done by looking for peaks in ADC counts in the 2-dimensional space of pad-vs-time bucket, and then fitting the structures to obtain a centroid. Deconvolution of overlapping peaks can be attempted.

These positions are given in two locally-defined dimensions: along the drift and pad directions; the third direction is perpendicular to the padrow and is inaccessible (indeed, undefined) at the clusterfinder level. Typically, the information generated is a list of reconstructed "hits." Along with position determination, hit information from the clusterfinder should have the total charge associated with the hit (for particle identification), whether the hit is influenced by more than one track (merging), and- ideally- the uncertainty in the hit position. Characterization of the shape of the cluster is often useful downstream, as well.

Due to its early position in the reconstruction chain, some calibration tasks often get integrated into clusterfinders. These can include channel-wise t_0 offsets (which shift pixels in time by fractions of a time bucket, and so cannot be incorporated into the pixel table) and offline gain corrections (which can in principle be done on the pixel table prior to clusterfinding). Constants associated with these calibration tasks, as well as detector geometry, should be keyed in externally (e.g. from a database).

Previous experience in TPC experiments leads to well defined expectations on merging and resolution properties of the clusterfinder. These are perhaps best documented in the book of Blum and Rolandi; the characteristics and trends described there have been verified as well in heavy ion TPC measurements EOS, E895, and NA49.

Less well-determined from previous experiments are expectations relating to performance; in NA49, clusterfinding was significantly faster than tracking, while in E895, the reverse was true. While it is something of a technical detail, "reasonable" CPU performance is a requirement for any package in the reconstruction chain.

A final point worth mentioning explicitly: Clusterfinders in these experiments, as well as that of ALICE under development, also share a common deficiency- despite significant effort to do so, none return reliable uncertainties for the hit position. As a result, trackers in these experiments generally ignore the uncertainties returned by the clusterfinder, and replace them with a parameterization (sometimes by a constant number).

5.3.2 Review of existing implementation - TCL

TCL is a relatively old and simple package that was largely left neglected (except for frequent tweaks necessary to comply with changing infrastructure) for some time, and then patched/tuned/appended as needed for cosmic ray analysis or the addition of cluster shape characterization.

Early simulation studies documented relatively satisfactory efficiency and resolution (STAR Note 238). However, algorithmic improvements, fixes, and hooks for calibrations have been added over the years. More recent simulation-based evaluation studies have been hampered by the erosion of TCL-specific evaluation tools (see below). However the performance of the overall event reconstruction (essentially clusterfinder & tracker) in "real" cosmic ray, laser, and RHIC beam-gas events, in addition to the earlier simulation studies on the unimproved code, provides some confidence that TCL is ready "enough" for year-1 data.

- The committee recommends that a serious effort go into CPU optimization of the clusterfinder. During the review it was stated that this has not been a top priority until now. On a low-multiplicity event, clusterfinding takes ~25 times longer than tracking, a huge factor by the standards of any of the experiments mentioned above.

  Indeed, a timing profile performed just before the review revealed that a single geometry function called multiple times accounts for ~85% of the CPU time in the clusterfinder; offline discussion indicates that reduction of the number of calls by at least an order of magnitude will be trivial.

  It appears clear that the time is right to perform these simple hotspot checks, and do simple optimization.

- The committee recommends that more sophisticated use of currently existing STAR wide evaluation tools (in particular, the StMcEvent/StAssociationMaker) be developed for use with the clusterfinder.

  Historically, clusterfinder evaluation was performed via internal "index tables" and a "shadow pixel map" containing pixel-by-pixel information about GEANT tracks that contributed to the pixel. These methods have long ago been abandoned. While there was some discussion as to whether to revive them, we recommend applying the new tools.

  Since the new tools employ proximity tests to determine hit-wise associations, it is important that the slow simulator and the clusterfinder access the same database and perform the same corrections (or "inverse corrections" in the case of the slow simulator- see Sec. 5.1).

- Currently, the methods used by the clusterfinder are somewhat simplistic. In particular, no true deconvolution of overlapping hits is attempted; instead, single-peak fits are performed on the pixels local to a peak in the pad-time bucket space. Also, while the peak *finding* is truly 2-dimensional, the peak fitting is performed one-dimensionally separately in the pad and time bucket space.

  Other experiments have attempted more sophisticated techniques. For example, the E895 experiment (which deals with higher hit density than expected for STAR) began with the STAR clusterfinder, and incorporated true hit deconvolution and 2-dimensional fitting (at a considerable CPU-performance cost). At a considerably lower priority than the points above, the committee recommends exploring these possibilities.

- In light of the experiential fact that, without crossing angle information (available only at the track level), reliable position uncertainties cannot be obtained, the committee recommends not to invest effort in trying to calculate these uncertainties in the clusterfinder.

5.4 TPC Tracker

5.4.1 Committee's understanding of generic package purpose

Tracking software in an experiment like STAR is as important as any detector subsystem, and its heart consists of the TPC tracker. There are several different tracking approaches on the market, under evaluation, and under development, many (or a combination) of which may be appropriate for STAR. Here, we avoid the details, and simply state some tasks that the TPC tracking package should perform.

Starting with a list of all reconstructed hits (or directly from pixels, in some proposed approaches), the tracker should perform pattern recognition to identify "tracks," which are sets of hits all caused by the same charged particle intersecting consecutive planes of the TPC padrows. Either simultaneously with this, or in the same step, it should fit the track with a well-defined track model (e.g. helix), and return (at minimum) the following information: the 3-momentum and the 3-position of the particle at some point in its trajectory. The tracking model should be sufficiently complete so as to allow extrapolation of the track trajectory (e.g. to its closest approach to the primary vertex). The principle "output" of the tracker, then, is a list of tracks measured by the TPC.

In addition to the particle trajectory and momentum, tracks in the returned list should carry reliable estimates of the uncertainties of these parameters. Also, track information should include some idea (e.g. via chi-square or confidence level) of the goodness-of-fit, as well as quality-related topological information such as the number of hits on a track.

Since conditions (B-field, position of the primary vertex, track density) may vary, the tracker should be robust against reasonable variations in the tracking environment.

The tracker represents the level at which many compromise decisions are taken: maximal efficiency versus maximal purity, track splitting versus track merging, etc. Naturally, these considerations must be made in the context of physics analysis requirements, which this committee is not designed to discuss in detail. However, one expects the tracker's handling of these issues to be (1) well-understood, and (2) controllable (i.e. changeable) within reasonable limits.

5.4.2 Review of existing implementation - TPT

TPT is among the most visible, discussed, and studied software packages in STAR. The general algorithm is straightforward (not to say simplistic), although many details (allowing for gaps, boundaries, straight-line tracking for zero-field running...) of the implementation can be quite involved.

It begins by finding track ``roots,'' which are 3 hits on adjacent padrows whose clusters overlap in pixel (pad-bucket) space (or, for the inner sector, hits in a line directed at the center of the TPC). Conformal mapping of hit positions and linear extrapolation (follow-the-nose) are used to build longer ``segments'' from these roots, and the segments are then reshuffled and extended to form longer tracks. Finally, the track is fit with a 2-component helix (circle in x-y and line in s-z) to extract track parameters.

Overall, based on simulations, general experience of robustness over the past several years, and exercise through cosmic ray and commissioning runs, TPT is considered to be ``ready enough'' in terms of efficiencies, purity, etc. to start attempting physics analysis in STAR using its output. The committee finds that some points still deserve attention, however. Especially the first one listed should be addressed as soon as possible, hopefully before data.

- Hit-position uncertainties are crucial for good fitting and momentum determination, and especially for meaningful goodness-of-fit estimates. Most of the tracker exercises have been carried out using the fast simulator TFS, which does provide reliable uncertainty estimates. However, as discussed above, the clusterfinder does not (and likely never will) provide reliable estimates of the uncertainty in the hit position. The implication for real data is that chi-square (and other) quality variables, upon which downstream software relies, will be meaningless, and that inefficiencies/biases may to develop for large rapidity, low-$p_\perp$ tracks.

  The position uncertainties may be reliably parameterized in terms of local track parameters (i.e. crossing angles and drift length), which are known at the level of tracking. The committee feels a top priority must be to generate hit-wise position uncertainties based on the local track parameters in all cases- i.e. even for the fast simulator.

- In the TPC tracking presentation, a pattern recognition (root formation) bias was discussed; the magnitude of the problem had not been fully evaluated. This could lead to low efficiency or enhanced ghost track probability for low $p_\perp$ (tracks not reaching row 16) particles, if the primary vertex is not at the center of the TPC. It was stated that the route to elimination of this potential problem is understood, and a fix would take about 1 week's work. Instead of further evaluation of the magnitude problem, the committee recommends implementing the fix.

- The solution to the above point involves a rapid estimate of the position of the primary vertex. Since this position is useful to a number of reconstruction packages, the committee recommends that the estimated vertex position be made available to the "outside world" in some standard way.

- The committee perceives that a rather small group of people is simultaneously *developing/maintaining* the tracker as well as *evaluating* it, and recommends that much more evaluation be done by STAR collaborators outside of this group. This will produce more educated "consumers" of the tracker output; many of these consumers will be performing physics analysis, and should be intimate with relevant details of the tracker's behavior. Also, it should generate a greater volume of analysis-relevant feedback.

- In much of the evaluation discussed during the review, tracker evaluation centered largely on the correspondence between the reconstructed track, and the corresponding Monte Carlo track which was its *best match*, according to the number of hits in common. In the terms used during the review, reconstructed/generated track pairs with the highest "qfact" were mostly considered. The committee worries that evaluations focussing on the largest-qfact matches may miss important information on ghosts and momentum resolution, and thus recommends that further evaluation efforts not center as exclusively on the largest-qfact matches. These "further efforts" may provide a natural starting-point for the "external evaluators" referred to above.

- A specific technical comment related to evaluations: A conformal map is currently employed in the pattern recognition step of the tracking. For performance reasons, the hit uncertainties are not transformed. Conformal maps are quite nonlinear near the origin (inner padrows), and biases or hit-loss could occur there. The committee recommends a careful evaluation of the distribution of the innermost padrow of the first correct hit on a track, to probe for this potential problem.

- It was discussed briefly during the review that the tracker might run a "second pass" with looser cuts, which could be more efficient for non-primary or spiraling tracks. Also, various switchable specialized routines have been implemented, which try to merge spiraling tracks (e.g. electrons) for specialized physics analyses (e.g. photon reconstruction). While these issues were not discussed in detail in the review, the committee makes the simple recommendation that the effects of these specialized routines on "standard" analyses be carefully evaluated, before switching the routines on by default.

6 SVT Tracking

The committee acknowledges the excellent progress made by the SVT (SDD and SSD) software group in the development of SVT tracking software. The committee recognizes in particular the outstanding efforts of Helen Caines in the coordination and implementation of tracking software. We summarize below our views on the different packages currently developed and make recommendations for future packages implementations.

6.1 SRS – SDD Fast Signal Simulator

The simulations presented were based mainly on the SRS signal simulator. K. Wilson developed this simulator while at Wayne State University. The simulator takes GEANT hits as inputs and produces simulated SDD hits accounting for diffusion, Coulomb repulsion, noise, as well as finite crossing angles of the particle through the silicone wafers. It also performs hit merging whenever GEANT hits are found within a specific radius of confusion.

Although great care was taken by Wilson to design and implement the SRS simulator so it reflects the actual detector performance in terms of resolution and merging, it is nonetheless desirable to explicitly verify whether the SRS parameters used in the tracking simulations are appropriately implemented and set. An analysis based on the E896 data, or laser test performed on the bench might be appropriate for such verification.

6.2 SSS – SDD Slow Signal Simulator

The slow simulator is currently under development at Ohio State by a graduate student under the guidance of Helen Caines. A C++ code is being developed based on earlier works by Reed, Rykov, and Pruneau. The simulator is not yet in a state such that it could be included in the STAR reconstruction chain.

The committee would like to emphasizes that an actual simulator of the digitized SDD signals is expressly needed to perform truly realistic simulations of the detector performance and, in particular, to optimize the cluster finder. Although the simulation of digital signals is not as critical for the SVT as it is for the TPC because the expected occupancy of the SVT is much lower than that of the TPC, the slow simulator is nonetheless needed to properly account of noise effects (which might be more significant in the case of the SVT) and for merging clusters which can only be handled very approximately with the SRS package.

On the technical side, the committee recommends that the C++ SVT slow signal simulator be modeled on the TRS packages. Specifically, we suggest that a designed using clear separation of the different stages of signal generation, and making use of abstract interfaces to delineate these different stages might enable a flexible and powerful simulation tool.
Once the SSS package implementation is completed, we further recommend a detailed comparative analysis of the resolution and merging be carried to properly tune the parameters of the simulator. Given the time required to complete the C++ implementation, we expect that the code shall be completed when new SDD data are available from the seven wafer ladder positioned in STAR for the summer run. It should thus be possible to perform a comparative analysis of the simulator performance based on the new data.

Once the performance analysis is completed, the simulator shall then be included in the full STAR simulation/reconstruction chain.

6.3 SSD Simulators

The Nantes group has taken responsibility for the design and implementation of the SSD simulator, the SSD hit finder, and a new tracker, which performs an outside–in search of SSD and SDD hits based on seed tracks reconstructed within the TPC. The simulators are discussed in this section whereas the hit finder and tracker are discussed in subsequent sections.

The Nantes group has developed a fast simulator of the SSD, which enables a transformation of GEANT hits within the SSD into strip hits as actual signals will be readout from the SSD. The algorithm and techniques used within the simulator were very briefly discussed by Hypolite. The methods used in the implementation of the simulator appear quite reasonable although a longer presentation might have been needed to fully discuss the details of effects of variable crossing angles, finite signal-to-noise, and charge sharing between adjacent strips. The committee recommends the authors of the simulator should produce a “long” write-up on the simulator to describe it in better details. Efforts should also be done to adapt the existing code to the most recent STAR software convention and standards so it can be readily incorporated within the simulation and reconstruction chain.

6.4 SCL - SDD Hit Finder

The hit finder developed for the STAR SVT is based on code that was used in the analysis of the E896 SDD data. The code algorithm was clearly presented by H. Caines. It is however not clear whether the cluster finder code is currently in a state such that it can readily be used in the STAR reconstruction chain. In particular, it is the understanding of some members of the committee that the cluster finder used in E896 was tailored to the specificities of the E896 data (baseline shifts, noise, etc). One thus wonders whether the STAR version of the code carries those specificities. One may also envision that the actual SVT data will also have “features” of its own. The STAR SVT cluster finder will thus also require to be fine tuned.

The committee recognizes that Selemon Bekele, from OSU, currently has the responsibility for completing the deployment and maintaining the cluster finder. We emphasize the urgency of deploying a STAR/SVT version of the code.

6.5 SSD Hit Finder

The Nantes group developed an interesting SSD hit finder which uses the charge deposition on U and V strips to successfully identify multiple hits topologies as well as the simple single hit per strip topology.

In view of the limited time allocated to this presentation, many interesting details were left out concerning the performance of the hit finder. The committee was nonetheless impressed by the very large efficiency and purity achieved in the reconstruction. Such a high reconstruction efficiency and purity result in parts from the very low detector occupancy for canonical HIJING events. The committee notes that it would be prudent to consider the reconstruction efficiency and purity for much larger multiplicity events. One should also clarify the role of the finite signal-to-noise ratio in producing spurious random hits that might cloud or complicate the track reconstruction. As in the case of the SSD simulator, we also recommend a “long” write-up be produced by the authors of the finder to properly document its algorithm, as well as its performance. It would be advisable, in particular, to fully document the contribution of the 1-1, 1-2, and 2-2 topologies to the reconstruction efficiency and purity in greater details.

6.6 Track Finder

The SVT currently uses a standalone tracker based on the STK and SGR packages to accomplish track reconstruction. A TPC track to SVT point track-finder is also being developed by the Nante group. We review these separately below.

6.6.1 SVT Standalone tracker

The standalone tracker uses a combination of a so-called “grouping” technique and a follow your nose approach. The grouping code, called “grouper”, is used in a first pass to identify the high momentum tracks. Hits associated with tracks are tagged as such and become unavailable for further reconstruction passes. The follow your nose tracker is then run as a second pass to identify lower momentum tracks as well as tracks which do not originate from the main interaction vertex (i.e. secondaries).

The “grouping” technique amounts to identifying 3-4 hits clusters in the hits phi-theta representation-space. The technique is ideal for a fast identification of high momentum tracks which, typically, form tight clusters in the phi-theta representation space.

The follow your nose tracker is based on a more traditional approach where hits are found successively by extrapolation of track segments starting from the inner layer and searching for matching hits outward.

The committee recognizes that (helix) track finding based on a set of 3, or 4 points is clearly not very well constrained. Such a weak constraint can lead, in a standalone mode, to the reconstruction of a large number of ghost tracks. To be more specific, the identification of well formed, helicoidal tracks based on 3 hits solely relies on the chi-square of the phi-z fit. This fit is a linear regression with 3 points, and 2 fit parameters: the straight line is not very well constrained. This means that hits can be assigned to many tracks with similar values of chi-square, and it is practically impossible to distinguish the properly reconstructed tracks from the ghosts. This thus explains why so many ghosts are actually found in the tracking simulation presented by H. Caines. We note however that in spite of the weak constraints mentioned above, one can nonetheless tailor the reconstruction code to minimize the number of ghosts at the obvious expense of reducing the reconstruction efficiency. One should stress that data with a rate of 50% ghost tracks are quite likely to be of limited use for physics. The committee thus strongly recommends that a careful analysis be conducted to determine the inter-relation between the number of ghosts and the reconstruction efficiency. The emphasis of this analysis should be on secondaries which constitute “la raison d’être” of the SVT.

The committee also notes that the treatment and propagation of errors is currently not handled in the optimal way. Clearly, the use of two 2D fits (circles in x-y and straight lines in phi-z space) rather than a 3D fit does not lend itself to an optimal treatment. Although such a simplistic approach was sufficient to assess the performance and useful of an SVT addition to STAR back in the days of the STAR CDR, a better fit approach which account for full error matrices, and multiple scattering within the detector, is clearly desired. It is clear however that track fits based on 3 or 4 points may not practically be amenable to more sophisticated treatments: standalone tracking and fitting, except for the lowest momentum of interest, does not appear a very viable long term strategy for STAR and SVT tracking. (More below on this).

6.6.2 TPC Track to SSD/SVT Points Matching (vector to point)

The Nantes group has begun the elaboration of an outside-in tracker with track seeds selected from the track segments reconstructed in the TPC. The tracker is built as a multi-pass algorithm which proceed to first match high momentum tracks from the TPC with SSD and SVT hits, and iteratively uses lower momentum tracks to match as many points of the SSD/SDD as possible.

The results resented by L. Martin were quite encouraging. On the onset, this tracking technique appears extremely promising. The committee however wishes to formulate few remarks on the algorithm used in the tracker.

- We strongly recommend that the association of hits to the TPC tracks should make use of a tree structure: i.e. initially, SSD/SDD points should be allowed to be associated to more than one TPC tracks so one can evaluate which of the associations has the best quality rather than using, as in the analysis presented at the review, a "first tested gets the track" approach. One should however be careful with the tree-build algorithm so the tree size does not explode in size: not all associations may be built – a number of criteria must be used to avoid uninteresting associations. (Note however that in a fully optimized tracker, such criteria are likely to evolve as one proceeds to find lower momentum tracks as well as secondaries).

- The multi-pass approach starting with the highest momentum is excellent as it allows a "safe" clean up of a large fraction of the SSD/SDD points. One should however make sure that the TPC tracks are not subject to random associations with SSD/SDD points. To that effect, it is recommended that early passes should include the main vertex i.e. one should try to associate SSD/SDD points which fall near/on an extrapolation of TPC tracks leading to the main vertex. This insures that the easiest tracks to be found, the high pt primary tracks are properly assigned and given priority in the tree based search of hit associations.

- The TPC tracks should be first sorted in order of decreasing momentum. The search can than proceed from the highest momentum to the lowest without any particular biases. We suggest that the use of track groups based on momentum intervals as it appears to be currently done may lead to pathologies which could be difficult to understand while it appears a lot safer, and just as simple, to systematically proceed from the highest to lower momenta based on a sort.

- The search algorithm should include the possibility to turn off a layer of the inner detector: i.e. on the onset, the tracker should be built to accommodate either a three-layer SVT, or an SVT+SDD four layer detector. This way, the tracker may be used during year one, with the SVT alone, just as well as in year two.

- The committee acknowledges the effort to explicitly account for scattering on non-active materials within the detector. We however recommend that a Kalman filter approach would readily solve the problems involved in taking scattering into account while the re-use of existing Kalman code, or at the very least modeling new code on existing Kalman codes could significantly speedup the implementation and deployment processes. The Kalman filter technique also offers the advantage of an optimal treatment of hit position errors.

- The committee also recommends that in the evaluation of the algorithm, one should test the relative merits of various pre-sort on TPC track quality (in addition to the momentum sort). Quality sorts might be based on the track length (i.e. number of hits on the TPC track segment), chi-square, etc.

6.7 SVT – TPC Track Matching (Vector-to-Vector)

The results presented on SVT and TPC track matching reflect the difficulty of the task and need further attention. Members of the committee suspect the poor matching performance may in part result from a (i) a non-optimal choice of the matching surface (i.e. the surface where both TPC and SVT tracks are extrapolated for the purpose of attempting position and direction matches), (ii) the limited momentum resolution of the SVT, (iii) improperly accounted for scattering effects in the inner layers (the radius of low momentum tracks changes has they reach outer layers of the SVT and the TPC – this entails a bias in the association of SVT tracks to those of the TPC; (iv) inappropriate or too stringent cuts used in the associations.

The committee suggests that if the SVT software group wishes to pursue the current vector-to-vector matching approach further, a significant re-write of the code in C++ might be in order. The algorithm should enable many-to-many associations: one should first build all plausible associations of SVT tracks to TPC tracks (in C++, this amounts to building a multi-map). One should then proceed to fit the tracks and sort them in order of decreasing chi-square. The best matches are thus trivially obtained from the sorted list: only then should one require one-to-one matches and tag the track segments as matched. It might be also be appropriate to pre-sort the TPC tracks based on quality (number of points or chi-square) as well as momentum in order to guarantee that the best tracks are matched first and removed from the set of match-able tracks.

6.8 Generic Comments on SVT-TPC Matching, Errors, and Performance Evaluation

The strength of the SVT lies in its capacity to provide a very accurate primary and secondary vertex positions, whereas, its performance as a standalone tracker, is intrinsically limited by the small number of layers, and the sizeable multi-scattering effects. The absence of a-priori knowledge about the primary or secondary nature of the tracks, in particular, further complicates the task of SVT tracking. The somewhat limited matching efficiency results presented are no doubt the best indicator of the difficulty of the task at hand.

The committee would like to stress that the vector-vector matching approach, as presented, is obviously limited in its usefulness because of (i) the rather limited efficiency, and the large ratio of false associations obtained, and (ii) the fact that the vector-to-vector approach, as used, may be intrinsically inadequate (or at the very least incomplete) for the treatment of secondaries given that by their nature, secondaries do not always produce hits in the inner layers of the SVT. We thus propose that the SVT group (including Nantes collaborators) while maintaining an optimization effort of the existing standalone tracker and matcher should invest seriously in the development of a vector-to-point matcher in the spirit of the work presented by the Nantes group. We stress that in terms of CPU usage, and track recognition time, the use of separate trackers for the SVT and TPC does not seem an optimal approach given the combinatorics involved in first searching for tracks in both SVT and TPC, and then attempting to connect these together to form longer tracks covering both detectors. An outside-in road finder using simultaneously both SVT and TPC hits should offer easier track recognition and reconstruction capabilities (inclusion of SVT points better constrained), and most likely a lower CPU usage.

We re-iterate that a proper treatment of the position errors is urgently needed in order to permit a reliable evaluation of the track quality. We also recommend a Kalman filter based method for track fitting and quality assessment.

7 Global Tracking

The committee would like to acknowledge the efforts of Spiros Margetis in establishing a credible global reconstruction. The committee recognizes the fact that the tasks of global reconstruction in year-1 and all future years are quite distinct and therefore we chose to discuss the relevant issues in that order.

7.1 Year-1 Global Tasks

In year-1 global reconstruction provides the following: track re-fitting in the TPC on the basis of a Kalman filter/fitter method, reconstruction of the event vertex, track re-fitting with the vertex on the basis of a Kalman filter/fitter method, PID information from all subsystems, TPC alignment on the basis of tracking, pre-analysis code for kink and v0 finding in the TPC, write programs for the DST output. These tasks are well addressed by the existing code.

Tasks that were not sufficiently addressed for the year-1 physics program are the track extrapolation to RICH and EMC. Spiros stated that the tool to extrapolate exists, but no results were shown (action item). We recommend in this context to store position and tracking parameters at the first and the last point in the TPC (using the Kalman fitter).

Regarding the Kalman fitter program, the actual improvements on the physics have to be better documented. The program should not only be used as an application for V0 finding cuts, but also as a generic fitting program. The improvements in the track errors were nicely documented, but they should also lead to an improvement in momentum and energy resolution at momenta higher than 300 MeV/c. Presently the TFS errors are used and we believe that switching to the slow simulator will make the error improvements more realistic.

Work on the Kalman fitter should include the primary vertex and thus requires a material propagator program (e.g. GEANE) that allows the inclusion of effects based on the IFC, gas, and beam pipe material. GEANE seems to run fast, but there might have been mistakes in the way the program was used, which documents that the material propagation studies are still in the early stages and thus have to be reviewed in the future after the program has been established.

The primary vertex finding program seems to perform well, but it seems to also cause some problems during the running of the BFC. Thus we recommend to re-write the code and make it more stable. Tracks should be weighted on the basis of the multiple Coulomb scattering and the performance has to be optimized in particular for the year-2 configuration. Presently the improvements from year-1 to year-2 are only a factor 2, which is in contradiction to the vastly increased impact parameter resolution when including the SVT.

7.2 Year-2 and Year-3 Global Tasks

For a detailed discussion of the two TPC-SVT matching approaches developed in parallel, i.e. track-to-track vs. track-to-point, we refer to section 6.6.

The tasks of the global reconstruction in year-1 and year-2 are very different. And if the SSD will not be available in year-2 (which is very likely), then the year-2 tasks will be different from year-3 tasks.
For year-2 an execution sequence has to be established that defines the matching procedure or procedures between SVT and TPC. For year-3 this code has to include the SSD.

For any kind of matching (vector or space point) we recommend to evaluate the radius distribution of the innermost correct point on every TPC track to evaluate the gap between TPC and inner tracking and thus estimate the extrapolation.

The TPC track to Silicon space point matcher as presently developed by the French groups should be finalized (within two months) and tested in both configurations, with and without the SSD. The code has to allow track tree formation (hit sharing) in the SSD. Also, material dependencies, e.g. dip angle, might have to be taken into account.

We also recommend that the SVT/SSD groups be charged with working out the details of the two matching approaches (track to track, track to space point). It should be the responsibility of the inner tracker to connect to the TPC, not vice versa. These programs should then be integrated into the global reconstruction for a global re-fit.

7.3 Manpower

We believe the group is seriously understaffed and fully agree with the view of the Project Leader that at least 2-3 more full time people to work on (global) tracking are needed in the near future to accomplish the tasks.

8 Future Planning

In his final remarks, Spiros Margetis in his position as Offline Reconstruction Leader, presented plans for further developing, improving and evaluating the tracking software. He distinguishes between projects that can addressed during the next few months (short-term) and long-term projects which, although not being of high priority for year-one running, need to be planned and organized as early as possible in order to succeed. In the following we comment on the long term planning only since many of the short term issues were already covered in the previous sections. In general the committee recognizes the short-term plans as reasonable, especially since they address problems that are also part (subset) of our findings.

8.1 Long Term Plans

8.1.1 Committee's understanding of proposed plans

The plans presented to us include the development of a new modular TPC tracker based on Kalman techniques. The R&D efforts as well as the implementation is conducted and performed by a dedicated group that is not in place yet. In addition the plan foresees to develop and use Kalman based propagator tools for global tracking and, depending on the outcome of the assessment tests, new improved tracking/matching algorithms. The intention is to provide a uniform environment where tracking algorithms can be tested, and which will facilitate the extension of the TPC tracking into the SVT.

8.1.2 Comments and Recommendations

In general the committee welcomes the plans as presented, although it feels that the detail of information available is not sufficient to fully understand their implications. This is in part due the fact that the reconstruction group itself is still reflecting on these issues and that it has not yet finalize their detailed plans. We therefore give the following recommendation in the hope that they will help to direct future efforts. Please note that we are **not** recommending a specific approach or technique but rather suggest a scheme on how to possibly approach and organize the effort.

- The Reconstruction Project Leader should officially form an R&D group which aims at developing an improved and coherent tracking approach incorporating all tracking detectors.
- It should be lead by an experienced (senior) person with sufficient insight in the matter.

- The group should be open to talented scientists with sufficient programming skills who are willing to devote a considerable amount of time into the effort. We estimate the need for at least three persons over the period of at least one year.
- Persons involved in the current tracking efforts should be fully integrated. Even if they do not wish to play an active role, it has to be assured that experiences gained during the past years are incorporated into the new effort.
- It seems advantage to work in close collaboration with experiments facing similar problems (e.g. ALICE, ATLAS, BaBar) thus taking advantage of their experience, findings, and (possibly) existing code.
- The *scope* of the effort should be well documented and a set of milestones should be defined precisely: A detailed text should be prepared, describing the milestone and the date of completion.
- A person responsible for the milestone must be designated.
- An estimate of the manpower and required programming skills must be given.
- The criteria for successful completion of the milestone must be clearly established.
- Consequences of failure must be indicated.
- The committee recommends that the group does not focus initially on *one* approach only but rather investigate alternate techniques before making final decisions.
- Once the group agrees on a specific approach their findings should be presented to a larger audience for review before the code gets implemented. A document should be written which explains the proposed concept and structure for the software.

All efforts have to be balanced vs. the need to maintain and, where possible, improve the current implemented tracking software, i.e. any new R&D efforts should not jeopardize current accomplishments. If possible, new algorithmic ideas should be tried out in the current framework before a major investment in manpower is dedicated to them.

9 Appendix

9.1 Agenda of the Tracking Review Meeting

Thursday May 4, 2000

1. Reconstruction overview, *Spiros Margetis*
2. TPC: overview, *Iwona Sakrejda*
3. TPC response simulator, *Brian Lasiuk*
4. Cluster/Hit finding, *Raimond Snellings*
5. TPC tracking, *Iwona Sakrejda*
6. Cosmic test results, *Eric Hjort*
7. Evaluation tools, *Peter Jacobs*
8. SVT: Resp. sim./Cluster/Hit finder, *Helen Caines*
9. SSD: Resp. sim./Cluster/Hit finder, *Boris Hippolyte*
10. SVT-alone tracking, *Helen Caines*

Friday May 5, 2000

11. Global: Overview, *Spiros Margetis*
12. TPC track to SVT track matching, *Helen Caines*
13. TPC track to SVT point tracking, *Lilian Martin*
14. Global refit using Kalman/Implications to V0 physics, *Al Saulys*
15. Event vertex finding and primary track tagging, *Lanny Ray*
16. Track extrapolation/Primary fitting, *Lee Barnby*
17. Short/longer term plans, *Spiros Margetis*
18. Preliminary report, *Thomas Ullrich for the Review Committee*