STAR Tracking Components Review

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Executive Summary

The committee has reviewed Phase-I of the tracking upgrade project, including the new STAR geometry model (a.k.a. Abstract Geometry Model, or **AgML**), the Cellular Automaton track seed finder (**CA**), and the STAR Virtual Monte-Carlo based tracker (**Stv**) components of the tracking upgrade. The purpose of the review was to assess the design, performance, and integration of these components with the STAR tracking software package and to help make decisions regarding the usability of the software and integration timeline.

Very briefly, we find that AgML and CA are ready to be used in the STAR offline production chain. Stv is not; but can be made ready with additional work.

The charge to the committee and related materials can be found on the web at the following address: http://drupal.star.bnl.gov/STAR/node/21715. The presentations and follow-up slides presented at the review are posted at http://drupal.star.bnl.gov/STAR/node/22515 .

The review committee would like to thank the STAR software leaders (Jerome Lauret and Gene Van Buren), the tracking component developers (Yuri Fisyak, Viktor Perevoztchikov and Jason Webb), the S&C team (Lidia Didenko, Levente Hajdhu) for a productive and highly organized review. We would also like to thank the group of testers that presented results during the review: Feng Zhao (for *LFSpectra*), Anthony Kesich (for *Heavy Flavor*), Paul Chung (for *BurlkCorr*), Duncan Prindle (for *JetCorr*), Grant Webb and Justin Stevens (for *Spin*), and Ramiro Debbe (for *UPC*). The committee thanks Jerome Lauret for organizing the test productions, performance tests, and the review. We note that an impressive amount of work went into the code development and testing exercises, thus putting the project on a good path towards integration with the full STAR tracking software system.

Committee Recommendations

AgML:

The design, implementation and present level of performance of AgML were found to be in a mature state and capable of providing STAR geometry configurations for years 2001-2010 in both STAR geometry formats: Geant3/AgSTAR and TGeo. The model is also found suitable for the description and integration of future detectors. We believe that the official deployment of AgML for STAR simulation and production can proceed at the earliest possible time, pending resolution of minor track losses and material discrepancies (detailed later) under the guidance of S&C Leadership and STAR Physics Analysis Coordinator. After deployment, AgML should become a single source geometry model for STAR. The estimated final project delivery time (according to the developers) is early February of 2012. We point out the importance of addressing the handling of misalignment between detector components before AgML is officially deployed.

CA track seed finder:

The Cellular Automaton seed finder used with the Sti-tracker has demonstrated significant improvements in the tracking efficiency (particularly for high multiplicity events) and is found to have a positive effect on the CPU-usage for event reconstruction. For the tracking part of the reconstruction chain, CPU performance has been shown to improve by 10-30%. The average improvement in the track reconstruction efficiency was found to be at the level of 7% and 2% for global and primary tracks, respectively.

These improvements warrant endorsement of CA as the official new seed finder for STAR. Final track-quality cross-checks for specific data selection (detailed below) still need to be completed. Remaining integration and support issues associated with the use of external packages (mentioned later) need to be addressed as well. At the same time, the committee feels that no additional review is required for the cross-checks requested, and should be handled by the S&C Leadership and PAC directly. The desirable time frame for deployment of the software for data production is early January of 2012 (for any next official data production in the year 2012).

Together with the STAR version of the CA seed finder, results from recent work on CA optimization by GSI colleagues were presented. The CA tracking algorithms look extremely promising for other STAR applications including the High Level Trigger and online reconstruction applications. It appears that it is possible to keep CPU utilization to less than 50 ms per STAR minimum bias 200 GeV Au+Au event. These achievements are quite remarkable and further developments within the STAR HLT team are strongly encouraged. However, we advise against importing the newer CA codes into the STAR offline framework and we recommend that future STAR CA seed finder optimization efforts (for use in offline) should be stopped because potential gains from adopting/testing of the newer versions are undermined by the limited manpower available for the offline production.

Stv multi-detector tracking:

The redesign of the current STAR Tracking code is of critical importance for the future STAR physics program. The current STAR tracking package (Sti) is limited by its inability to accept non-cylindrical symmetry and therefore is unable to integrate some of the new, especially forward, STAR detectors. After reviewing the relevant presentations, we endorse the continued development of the Stv package as the future tracker for STAR. The code promises to have the capacity to extend the tracking to a truly integrated approach, but remains a TPC-only track finder at the moment. Multiple performance issues (detailed below) were discovered during the review. The implementation of the tracker seems to be progressing well but the reviewed implementation of Stv is not ready for production.

The committee notes that the implementation of an integrated tracking framework is crucial for FGT software development leading up to and during the upcoming engineering run. We recommend to make the Stv code immediately available for this work, which should be a synergetic effort involving both the S&C and FGT teams. We note the need of PPV Vertex Finder modifications to work with StEvent tracks, and thus become compatible with Stv.) To make these efforts most productive, critical Stv problems (hit errors, chi^2) discovered in the review need to be given high priority and addressed under S&C/PAC supervision before the run 12. The current state of the Stv software is sufficient for the initial efforts of FGT integration in the upcoming engineering run; however it will not be sufficient for the analysis of the physics data which is scheduled to be taken in run 13.

The committee recommends that Stv be made ready for the production of run 13 data (with complete FGT integration and functional PPV VF).

Additional effort must be made before Stv can be adopted as the official STAR tracking code. Issues that require further investigation are tracking efficiencies, purity, and p_T resolution for high p_T tracks (particularly 20-60 GeV/c). In addition, issues such as the modification of the PPV Vertex Finder, stability of Stv output for high pileup p+p events, CPU use and optimization, and integration of the existing detectors into the VMC tracker code should be addressed before the deployment. Deployment in the production chain should be preceded by a full test and another review.

We believe that the integration of the new Stv tracker into the STAR analysis framework is a major task and can be accomplished in time for Run13 data production only if sufficient manpower is allocated. We recommend focusing the effort of the core group of developers, for the coming year, on Stv related work. We believe it is appropriate to qualify Stv-related work as a STAR Service task of critical importance and an appropriate request to the STAR Council members should be made for additional manpower.

For the proper and timely evaluation of the tracking improvements, we recommend that the PWG conveners maintain a 'tester task force', with the goal of providing at least one person from each Physics Working group for future Stv testing and evaluation. We also recommend that incoming detector subsystems (FGT, HFT, …) provide liaisons to work with STAR S&C on these integration tasks. The following comments address the specific charges to the committee, make additional recommendations, and highlight issues that should be addressed in the future.

Detailed Comments Regarding AgML

<u>Readiness:</u>

The readiness of the description language and the related tools has been sufficiently demonstrated. It has been shown capable of generating Geant3/AgSTAR and TGeo format geometry from a single source geometry description.

AgML has been found suitable for integration with the Forward Gem Tracker (FGT) and a geometry realization was already presented to the committee. The FGT group's concerns regarding compilation and visualization complication were addressed during the review.

The suitability to describe future complex detectors, such as the HFT, has been demonstrated with the implementation of similar scale geometry of the SVT detector.

The implementation of the AgML for support of multiple geometry configurations throughout previous RHIC years has already began, but not yet completed. Some issues with the agreement between AgSTAR and AgML versions are noted and require more work before a satisfactory resolution is achieved. The recommended approach to ensure consistency is to support both geometry packages for the past years, but adopt exclusively AgML based descriptions for year 2011 and later, and for new detectors and R&D.

Details of AgML integration in the STAR framework were presented and found adequate. The adopted naming convention is mnemonic and the readability of code is sufficient. The existing documentation provides adequate information to assist users in understanding the existing code and provides a good foundation for adding new detectors to the STAR framework.

<u>Performance:</u>

In general, there is good agreement between AgML-generated and AgSTAR geometries. The material in front of the TPC tracking volume, which would have a significant impact on tracking, is modeled to better than 1%. Some areas of disagreement are found inside the TPC, and it is recommended that these issues are addressed before AgML is deployed. Configuration problems for MTD and issues with PMD AgSTAR --> ROOT conversion were reported, and found to be less critical for proceeding with the project.

A hit-by-hit comparison of starsim simulations using the AgSTAR and AgML geometries as input was presented. There exists an excellent correlation between AgML and AgSTAR hits in starsim simulations for most detectors. Minor hits disagreements in the EEMC and ESMD detectors were observed. The committee recommends that the source of the discrepancies be investigated.

From a tracking perspective, AgSTAR and AgML based geometry inputs to the Sti tracker, yield good agreement in terms of number of global and primary tracks per event. Minor losses were found at low p_T and a few specific areas of space; we recommend that these issues be resolved before AgML deployment.

<u>Future developments:</u>

The committee compliments the development team for the attention given to ensuring backward compatibility for the geometries and we do not foresee it becoming a cause for concern. The framework imposes no constraints preventing the usage of prior year detector configurations.

It is expected that the current implementation will have no detrimental impact on the Embedding chain. However, with the advent of the VMC-based tracker, a single chain/single geometry source for the embedding will become a real possibility and it is recommended that such developments go hand-in-hand with the tracking revamp project.

No implementations for the non-perfect geometries have been presented, though existence of such capabilities was expressed. Future development should give priority to proper misalignment and calibration handling.

The AgML code provides an agile framework for addressing future morphing of STAR into eSTAR, and we encourage such applications. It is suitable and immediately ready for integration with Geant4 or higher.

Detailed Comments Regarding the CA track seed finder

<u>Readiness:</u>

The readiness of the Cellular Automaton seed finder code has been successfully demonstrated. The documentation of the code and methods, currently existing in the form of various conference links should be consolidated and completed by the time of CA code deployment. We also find that the CA code does not adhere to the STAR coding standards, has no header describing what the code does, and has insufficient comments to guide one through the code. Use of external packages (TBB and Vc) is a concern for the future compatibility, and should be addressed within S&C team.

The CA seed finder is found to be easily integrated with the Sti tracker. Successful integration was also demonstrated for the Stv version reviewed.

The CA code is written in C++ and in its current implementation does not raise concerns regarding multi-platform portability.
The integration capabilities of the CA seed finder for other detectors, FGT particularly, were discussed briefly, and the ease of integration was noted by the developers, however, this statement could not be reviewed by the committee.

<u>Performance:</u>

A comparative performance analysis was presented for StiCA (Sti tracking with the CA seed finder) vs. Sti, with tracking reconstruction studied via real and simulated data as a function of p_T, ϕ, η, and multiplicity separately for primary and global tracks. The addition of the CA seed finder has consistently improved the tracking reconstruction efficiency for all samples studied. The improvements presented amounted to 3-8%, with the greatest improvement achieved for higher multiplicity events.

The most dramatic efficiency improvements were presented for the tracks over the "troubled" TPC sectors (e.g. sector 20), raising concerns about the quality of recovered tracks. We recommend that these tracks should be re-evaluated to ensure no addition of ghosts, fakes, or split and mismatched tracks.

Overall, the following parameters were cross-checked with Monte Carlo data and found to be of the same quality between Sti and StiCA: hit residuals and pulls, dca, chi^2, and p_T and ψ resolutions and pulls. The track-by-track comparisons of the real data showed positive shifts in the average number of hits per track for StiCA (plus one point on average), 7% and 2% average improvement in the track reconstruction efficiency for global and primary tracks, respectively, and no measurable changes in the transverse momenta measurements for either primary or global tracks.

Minor improvements were noted for the CA seed finder when run with Stv; the choice of the optimal seed finder for Stv should be reevaluated at a later time when Stv is ready for deployment. It should be noted that the increased track reconstruction efficiency in troubled sectors that was observed in StiCA, was not evident in StvCA.

The CPU performance for the tracking part of the reconstruction chain, with CA, was improved by 10-30%, depending on detector occupancy.

The results presented by the PWG-dedicated group of testers confirm the findings detailed above. The UPC group reports similar/slightly higher efficiencies for the StiCA. LFSpectra results show higher efficiencies for global tracks, resulting in higher efficiencies for the V0 reconstruction, while measured width and masses of the weak decays are reported comparable between StiCA and Sti. HF reports higher number of Upsilon candidates found with StiCA. The jet reconstruction efficiency reported by Spin is 1% higher for StiCA. Higher reconstruction efficiency for the W is also reported. Jetcorr reports a higher numbers of good global tracks found with StiCA, and good agreement between the number correlation parameters between Sti and StiCA. Finally, the distribution of the number of possible points for StiCA reconstructed tracks is found to be wrong, which needs to be fixed before full deployment in STAR.

Future developments:

We recommend ceasing STAR CA seed finder optimization efforts for offline production, and redirecting any future CA developments for online application to the HLT group. For the offline application of the reviewed version, we foresee no major risks associated with the use of external packages at the moment. No risks are found associated with the move toward a Stv/TGeo approach.

Detailed Comments Regarding the Stv Tracker

Readiness:

The initial phase of Stv development and integration is ongoing, the results are promising, but the code is not ready for STAR wide use.

The committee finds that practically no documentation is available on the method (in general), and its specific implementation. The committee recommends that documentation issues be addressed in parallel with Stv developments.

The Stv code is written in C++ and is expected to be portable to multiple platforms. It is ready for integration into the STAR framework.

The Stv code is found to take full advantage of TGeo based geometry. There are no obvious limitations for migration of STAR toward post-Geant3 versions.

The ability of the Stv to properly account for the material budget is unclear at the moment, as performance tests uncovered significant losses in the dead material.

Problems were found concerning the use of an inadequate Vertex Finder (Minuit VF) in Stv for p+p events with high pileup. The PPV VF needs modification to work with Stv tracks stored in StEvent, after which a reliable evaluation of Stv for p+p events can be performed. While these issues do not seem insurmountable, the committee points out the importance of optimizing PPV VF within Stv, especially in high pile-up conditions, and this may take extra effort. Work toward optimization should be pursued by the developers from both, S&C and VF teams.

The implementation of the track extension method into volumes other than the TPC was not reviewed by this committee. The validity of an extrapolated covariance matrix was not discussed. The developers stated that track projections to the other detectors can be easily implemented, but no specific details were discussed and we believe no such work has been done to date. The committee strongly recommends that integration of all sub-systems, for example FGT and TOF, into the tracking model should become a major focus of the project.

The Stv is intrinsically streamlined towards integration of forward detector geometries but no such work has been carried out yet. In parallel with this recommended critical development, the committee recommends that appropriate documentation needs to be created for the track predictors to other detector elements, with detailed workflow of the algorithm to be worked out with the relevant subsystem groups.

The possibility to have track fits using different mass assumptions at low transverse momenta were briefly discussed, but it was reported to the committee that no such developments exist at the moment.

Performance:

The comparative performance analysis was presented for Sti vs Stv and StvCa, with tracking reconstruction studied via real and simulated data as a function of p_T, ϕ, η and multiplicity for primary and global tracks separately. The Stv-family of trackers have shown similar tracking reconstruction efficiencies compared to the base-line Sti tracker for the tracks with transverse momenta below 2 GeV/c. For high p_T tracks above 20 GeV/c the reconstruction efficiency decreased by nearly a factor of two, as shown by spin PWG evaluation. But, on a positive note, it should be noted that a significantly lower number of cloned and ghost tracks were found with the new system.

At the same time, the p_T dependence of the tracking reconstruction efficiency is not entirely understood, especially in terms of the degraded resolution of charge sign reconstruction. Also, significant losses in reconstruction efficiencies were found for the TPC dead-material (sector boundaries; the losses upward to 90% of all tracks) in comparison to Sti results.

The following parameters were cross-checked with Monte Carlo data, and could be summarized as follows: hit pulls, dca distribution width, chi^2 and p_T resolution are found worse in Stv than in Sti (the adverse effects noted ranged between 50% to a factor of 3). The hit residuals looked smaller with Stv, which was pointed out to be the potential source for a number of problems uncovered later. The ψ resolutions and pulls were found to be slightly worse for Stv compared to Sti.

The track by track comparisons showed a gain for the Stv in terms of average number of hits per track-by-track, with about two extra points on average. The average improvement in tracking efficiency for the low p_T tracks was on the order of 2% for global tracks and 1% for primary tracks.

Track by track comparison of the Stv and Sti trackers on the real data have shown similar momentum resolution and pulls for inclusive tracks, however systematic and opposite shifts for positive and negative tracks, were observed between tracks found by the two trackers. The discrepancies are shown to grow with the transverse momenta. We emphasize the importance of understanding this effect in the future studies.

Inclusion of the CA seed finder into the Stv reconstruction was found to have very minor effects on the overall efficiencies, and preserved all the features discussed above. It is unclear at this point which type of seed finder would work best with the final version of the Stv, thus we recommend this question to be addressed by the next review.

There was no direct energy loss comparisons presented for Stv with regard to Sti; PWG tester reports indicate potential minor shift between the two.

The committee finds insufficient supporting evidence with regard to Stv's ability to handle low multiplicity high pile-up events. As pile-up is expected to become a major complication for the future physics runs for p+p, we recommend this issue be studied in details and presented for the next review before Stv deployment.

The current version of the Stv tracker is found to require twice the CPU resources (per event) used by Sti. It is not immediately clear where the timing losses are coming from. The developers stated that optimization rather than algorithmic change is needed to alleviate this problem. The committee recommends addressing this matter before a full deployment is attempted.

The reports from the physics analyses of the PWG-dedicated testers bring additional problems to the table. A subset of results discussed included the following items. Stv and StvCA have been reported to have lower efficiencies and unusual phi distributions by the UPC. The efficiencies of Stv and StvCA look significantly lower than those from Sti from Jetcorr correlation studies. The widths of Lambda and AntiLambda become broader in Stv and StvCA data samples, compared with Sti samples. On the contrary, in HF tests higher efficiencies are reported for Upsilon candidates with StiCA and Stv, but significant mass shift has been observed at the same time between the Sti and Stv family. Spin group reported major losses in jet reconstruction efficiency (factor of 2) due to the loss of low pT tracks in Stv compared to both Sti and StiCA. The charge sign discrimination at high p_T deteriorates significantly while switching from Sti to Stv. The yield of reconstructed Ws has increased by 10%, possibly due to lower jet reco efficiency of 30% which weakened jet-veto part of the algorithm. The fraction of background events in the W analysis has increased by 25%. Jetcorr tests uncovered Stv problems with saving of global tracks to MuDst format; also they report incorrect results for p_T and y_T correlations in Stv. The number of possible points distribution for Stv reconstructed tracks is found to have a maximum at an unexpected value.

The committee consensus is that Stv is not ready for physics.

Future developments:

Multiple issues of critical importance were discovered for Stv and presented during the performance review. Hit residuals and track chi^2 should be the first problems to be addressed. Tracking inefficiencies, p_T and charge dependences for reconstructed tracks, and charge separation for high p_T tracks need to be reevaluated after Stv tuning and optimization. Implementation of the track extensions to other detector volumes is necessary for the Stv to become the truly integrated STAR tracker. We recommend a synergetic effort between S&C and FGT teams to carry out the first such integration attempt. Extension to the TOF detector is recommended to be next on the priority list. The recommended timeline for the deployment is for the Run13 production, preceded by a full test and another independent review within the next 6 to 12 months. Future efforts in the Stv development are also needed to integrate BTOF and ESMD detectors, incorporating the possibility of reconstructing tracks by starting from detector volumes other than the TPC.