StarBASE: Fighting and Tracing Geometry Changes by Applying Differential Studies

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Abstract. The STAR experiment has evolved significantly since it first began operation. Detector subsystems have been added, removed, and/or significantly modified between (and on occasion within) the 10 RHIC runs. Mistakes, oversimplifications and bugs in the geometry model have been discovered and addressed as simulations are confronted with ever-more-precise data. We therefore maintain over 30 distinct versions of the geometry in order to support simulation needs related to ongoing analysis, upgrade studies and historical reference.

In order to help us understand the impact of geometry changes on detector response in our various simulation productions we have developed the StarBASE application within the VMC framework. StarBASE provides the capability to perform detailed comparisons of the material and medium properties between any version of our geometry and a baseline version. This allows us to perform regression tests between library releases, to ensure that changes to one part of the geometry do not have unintended consequences in another part of the geometry, and to help to quantify the impact of an evolving geometry on different physics measurements.

1. Introduction

The STAR experiment [1] at the Relativistic Heavy Ion Collider (RHIC) has been taking data since the first RHIC physics run in 2000. Pictured in figure 1a, the STAR detector (Solenoidal Tracker At RHIC) was designed to study heavy ion collisions at center-of-mass energies up to \( \sqrt{s_{NN}} = 200 \text{ GeV} \) and polarized proton collisions up to \( \sqrt{s} = 500 \text{ GeV} \). Installation of much of the detector was staged during the yearly RHIC shutdowns between runs; major subsystems and upgrades were completed at pace to match the physics reach of the detector to the anticipated performance of the collider. The evolution of the detector is illustrated in figure 1b. While the detector has remained essentially unchanged since 2009, several major upgrades are planned over the next decade [2] which will further extend the physics capabilities in STAR. Our experience has shown the need to identify and document changes to the geometry model as they occur. In this paper we discuss the application of a geometry differential analysis for performing basic quality assurance (QA) of the STAR geometry model.

2. The STAR Geometry Model

In order to support the simulation and reconstruction of the various data samples, a detailed software model of the detector geometry is maintained. The STAR geometry is implemented in the Advanced Geant Interface (AGI) language [3]. When compiled and linked with a dedicated support library, this creates the GEANT3 [4] geometry used in our simulation package starsim. Our event reconstruction is based on ROOT [5] and obtains geometry information through the
ROOT geometry package [6]. In order to maintain a single source of geometry information, the ROOT geometries are produced from the AGI geometry using the \textit{g2root} application. For the long term maintenance and future development of the STAR geometry, we are migrating our model to an XML-based language which will be able to produce the ROOT geometries directly.

The rapid change of the STAR experiment presents some challenges in maintaining the detector model, and in migrating it to the new language. We currently maintain $\sim 35$ distinct versions of the detector geometry for use in simulating and/or reconstructing existing data sets. An additional $\sim 15$ models are maintained as reference for upgrade studies. Eleven different geometry models (one for each RHIC run) are continually updated to reflect our best knowledge of the detector geometry during their respective run periods. In addition to the development geometries, we maintain $\sim 25$ production geometries. Once a development geometry has been used to simulate and/or reconstruct a data set, it is elevated to production status. Production geometries are not updated, they are kept unchanged as a reference for the data set which they produced. The only changes which are allowed are minor bug fixes which have no impact on the physical response of the detector. This ensures our ability to reproduce the data samples at a later date.

Given the numerous versions of the STAR geometry we must maintain, the new detectors which we expect to integrate into the geometry during the expected upgrades, and our efforts to migrate our geometries to an XML-based language, we need a tool allowing:

\begin{itemize}
  \item Tracking and documentation of the changes to the geometry
  \item Regression tests to ensure that the addition of new detectors does not cause unintended consequences in the existing geometry
  \item Identification and elimination of mistakes in the geometry
  \item Validation of the XML-based geometries vs their AGI originals
\end{itemize}

We address these needs with a geometry differential analysis.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{star_detector.png}
\caption{(a) The STAR detector – y2010 to present. (b) The evolution of the STAR detector from y2000 to y2010. The magnet has been removed for clarity.}
\end{figure}
The depth of a volume $A$ is the total amount of material encountered by a particle traversing the volume. A running sum of the total depth encountered by track is updated and stored at each boundary crossing. Then the depth of the volume can be calculated by subtracting the depth on entering the volume from the depth on exiting the volume.

3. Geometry Differentials

When comparing two versions of a geometry model, we are most interested in three things: (1) the amount of material present in each detector volume and in front of each detector volume, (2) whether there has been a change in the material, and (3) the size and location of the change. The amount of material in a given detector volume is determined by calculating the depth of that volume as seen by a particle (geantino) originating at a reference point and passing through the volume on a straight line trajectory. We choose the reference point as the origin of the STAR coordinate system, rather than the intersection point of the colliding beams, in order to facilitate comparisons of geometries from different runs. The depth of the volume depends on the material, shape and size of the volume. It also includes contributions from any daughter volumes. The calculation of the depth of a volume is illustrated in figure 2. A geantino track is generated and propagated through the detector geometry. We keep a running sum of the depth $D_{\text{total}}$ which the particle has encountered. On each volume boundary, we increment the total as

$$D_{\text{total}} = \frac{\rho_x \times \Delta_{x_1}}{x_1} + \frac{\rho_c \times \Delta_{x_2}}{x_2} + \frac{\rho_a \times \Delta_{x_3}}{x_3} + \frac{\rho_b \times \Delta_{x_4}}{x_4} = D_{\text{out}} - D_{\text{in}}$$

where $\rho_v$ ($\chi_{0,v}$) is the density (radiation length) of the volume the track is exiting and $\Delta$ is the distance from the last boundary crossing. When the track enters a volume, we save the running sum as $D_v$. On exiting a volume, we can then calculate the total depth material contained within the volume as $D_{v,\text{in}} = D_{\text{total}} - D_v$. The geometry differential is simply the volume-by-volume difference in depths between the two versions of the geometry.
Figure 3. Left: Shows the material budget for the STAR Time Projection Chamber (TPC) in the y2006c and y2006g versions of the geometry plotted as a function of pseudorapidity. The solid (black online) histogram shows the material in the y2006c geometry. The dashed, hash filled (red online) histogram shows the material in the y2006g geometry. The percent change is shown at the bottom of the histogram, with the scale (blue online) at the right. Right: Shows the material budget of the five daughters of the TPC mother volume.

In order to calculate the geometry differentials, we have developed a Virtual Monte Carlo application starbase and a presentation utility differential. The developer first runs starbase on the two geometries he or she wishes to compare. When starbase runs, it first creates the ROOT geometries from the AGI originals. It then loads the ROOT geometry and iterates over the list of defined volumes. Three histograms are created for every volume present in the geometry tree. These histograms are used to store (1) the depth of material present in each detector volume, (2) the depth of material found in front of each detector volume, and (3) the number of geantinos passing through the bin of each histogram for normalization. Geantinos are thrown from a vertex of (0,0,0) along a specified set of straight-line trajectories. This ensures that subsequent runs will measure the depth of the detector volumes along identical paths through the geometry. The results are stored in ROOT files along with the geometry used in the respective runs.

Figures 3 and 4 illustrate some typical use cases of starbase. The figures are generated using the differential presentation utility, which produces a postscript data file (PDF) for each of the subsystems of the STAR detector. In figure 3, the large panel at the left compares the material budget of the Time Projection Chamber (TPC) of the STAR detector between two versions of the 2006 geometry. The solid black histogram shows the total TPC depth in the y2006c version of the geometry, while the dashed (hash-filled, red online) histogram shows the total TPC depth in the y2006g geometry. The (blue online) histogram at the bottom shows the differential (the difference in depths divided by the earlier y2006c geometry). The scale at the right denotes the percent change in the depth. In addition to the major detector subsystems, differential includes in the PDF files plots of their daughter volumes. The five smaller panels in figure 3 show plots of five of the daughter volumes of the TPC.

There were no changes to the TPC geometry code between the two revisions shown in figure 3, so we must see identical material budgets in the two revisions. Otherwise, changes made elsewhere in the STAR geometry are causing problems which must be eliminated. In this case, we see differences no larger than 0.001%. This difference is located in the TPEA volume, a structural support outside of the active volume of the TPC. The active volume of the detector,
the TPC gas volume (TPGV), shows an even smaller difference. The size of these differences is negligible, and attributable to round off errors in tracking through slightly different geometries sitting in front of the TPC. Examination of plots such as these for the subsystems of the STAR detector provide an important regression test when developing new detectors and/or refining the models of existing detectors. Furthermore, this process can be automated. The results of differential can be output to ROOT files and input into automated QA facilities as part of a library validation process. This will allow us to detect instances where developers introduce changes to their detector(s) which result in side effects elsewhere in the STAR geometry.

In addition to regression tests, the starbase application is useful for documenting changes made to the geometries. In 2005, several analyzes indicated that a significant amount of material had been left out of the geometry model for STAR’s Silicon Vertex Tracker (SVT). It was quickly determined that several cooling pipes had been left out of the geometry model. This resulted in the revised y2006g geometry model. Because we have several Monte Carlo samples using the y2006c model of STAR, it is important to document the amount of material left out of those data samples. This is especially important for the TPC, STAR’s main tracking detector, which completely envelopes the SVT. Figure 4 compares the material in front of the TPC between the y2006c and y2006g geometries. As can be seen from the leftmost panel, the amount of material encountered by tracks before entering the TPC (or its active volume in the upper right panel) has increased by 83%, from about 0.06\chi_0 to 0.11\chi_0. By providing such documentation, physicists who use the older data samples are better able to quantify and justify the systematic uncertainties in their analyzes.

4. Summary
The STAR experiment has changed significantly during its 10 years of operation. While the detector has not changed significantly since 2009, a series of upgrades are planned starting this summer which will further extend the physics reach of the detector. Our experience has shown that it is important to perform regular regression tests to track the changes to the geometry made by developers, and quantify the differences between different versions of the geometry. We are migrating our geometry model from the AGI language to a new XML-based language which will enable us to take advantage of current and future developments in the field of Monte
Carlo simulations. Therefore we have developed the *starbase* and *differential* applications. These applications provide the capability to track and identify inappropriate changes to our geometry model before they are propagated into a production library, provide a tool for developers to verify that their geometries provide a correct description of their detector, and provide the means to validate the new XML-based geometry model.

References

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