Geant4 Web Application Update and Pion Cross Section Simulation

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ABSTRACT

Geant4 (Geometry and Tracking) is an open-source simulations toolkit for the particle interactions with matter [1]. The toolkit is constantly validated as more experimental data becomes available and new Geant4 versions are released. The Geant4 web application [2] is the medium for users to access simulated and experimental data. The most recent developments of the web application make the interface more user-friendly, secure, and interactive.

I made use of various software suites to ensure user access to the central database was constrained. I also worked on adding a new pion cross section simulation to Geant4. The following is a description of the methods used in editing the web application and an account of the pion simulations.

INTRODUCTION

Geant4 is a toolkit containing physics models detailing particle interactions and their approximations at energy ranges from eV (chemistry) to TeV (high energy physics). Thus, Geant4's application domain includes high energy physics, nuclear studies, accelerator experiments, medical work, and space exploration. It is important to not only continuously add data and simulations to Geant4's repository, but also validate additions against other Geant4 versions and previous experiments. The Geant4 web application allows users and developers from all areas of interest to access experimental and simulated data via static image plots and data tables. The interface is interactive, it allows users to select different parameters (i.e. target material, beam particle, energy ranges, etc.) for study. My work with the web application added features to keep the web pages user-friendly and protect the database against malformed inputs; moreover, new pion cross section (simulation) test data will add more validation information to the Geant4 database.
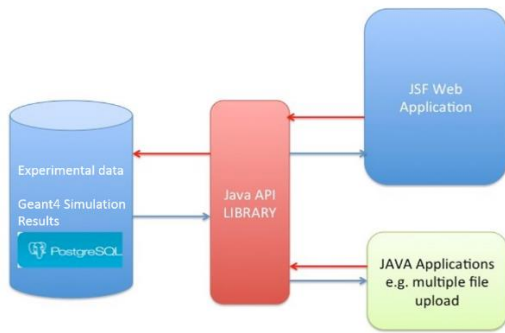
Figure 1: Software Components of Geant4 Validation Repository

WEB APPLICATION DEVELOPMENT

A. Malformed User Input Protection

Geant4 information is stored in a PostgreSQL relational database [3]. The data is in the form of images with meta data or raw data points. This meta data describes the test and lists the references for the experimental data and other parameters defining the test (i.e. beam particle, target material, etc.). The web application accesses the database through a java API, an abstract interface using a data access object (DAO) design pattern. It is important to keep the user's editing and access privileges to the database constrained to properly formatted requests. The API separates the user from accessing the storage database directly. The software components of Geant4's validation repository are depicted in Figure 1.

On the edit test page in the web application, the user—authenticated as a G4Expert—has the ability to display and edit the meta data associated with a particular experiment. In order to make sure the edits made do not conflict with the formatting schema in the SQL database, I added constraints and masks to the input fields. For example, the field "Beam" must be a string of less than 20 characters. New dictionary valued drop-down menus for fields

such as status, score, and scoretype also constrain the input to predetermined values. In this way, the user can only make approved changes to the meta data in the database, protecting against malformed user input.

The user is also now presented with feedback from the server if the entry submitted is incompatible with existing preconditions. Previously, the submissions would be rejected by the database and an error message would be buried in an obscure server log file, inaccessible to the user. Now, the database is protected and the user is clearly presented with an error message detailing the mistake, prompting a proper submission, as shown in Figure 2.
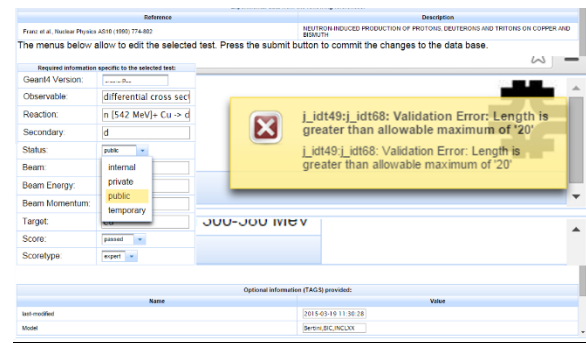

Figure 2: Masked and constrained inputs and error message from Geant4 edit test web page

B. Staged Delete

On the same edit test page, the Geant4 web application has a button for deletion of a test (set of data points) from the database. Once again, the editing and deletion privileges are only granted to an elevated class of users, G4Experts. We decided to change the process to increase oversight when permanently deleting information from the database.

This process involved the creation of a new, "superuser" user classification for the web application, which is granted permanent delete privileges. Thus, the G4Administrator class was born. The G4Adminstrator inherits all of the methods of the G4Expert in addition to

permanent database deletion privileges. The deletion process was changed to incorporate the G4Expert and G4Administrator roles. The G4Expert delete marks a test as temporary and permanent deletion is reserved for the G4Adminisrator. The G4Expert can delete a test from view from the general public using the same edit test page as before. Now, the G4Expert delete button changes the status of the test from public to temporary (the condition for imminent deletion). The G4Expert can undo this action with the same edit test page functionality. It should be noted the test is maintained in the database by this action. Then, the authenticated G4Administrator sees a temporary test marked for deletion by the G4Expert. Using the edit test page, the G4Administrator can now choose to change the test information as needed before either marking it public again (for general users without authentication) or deleting it permanently from the database.

C. Release Highlights Selection

Regression means each Geant4 version is compared to the previous ones for quality control. In the header of the Geant4 web application, there is a "Release Highlights" section which summarizes the achievements and changes made with each Geant4 release.

Previously, the header link sent the user to the most current Geant4 version's release highlights page. In order for the user to compare versions to see what and when changes were implemented, I added a Release Highlights Select page, accessible from the web page header. This release highlights page allows the user to select different versions of Geant4 and see their specific changes.

D. Default Display Plots

Interactive plotting functionality is one of the main features of the Geant4 web application. In the experimental data browser, the user can select a set of information by experiment and view the results in a plot or data table. Drop-down menus feature options for different plot parameters corresponding to meta data information in the SQL database (i.e. target material, beam particle, energy ranges, etc.). In order to give the user a functional starting point for all of the different variable selections, we decided to present the user with a default plot (and matching selections) for each experiment.

We sought to associate a default set of plots to each experiment in the SQL database. Previously, the plots (xyexpdata objects in the database) contained information about which experiments and references they were related to. This default display meant changing the database schema to have plot outputs (xyexpdata objects) reference unique experimental descriptions (expdes objects). These new, unique objects would contain all
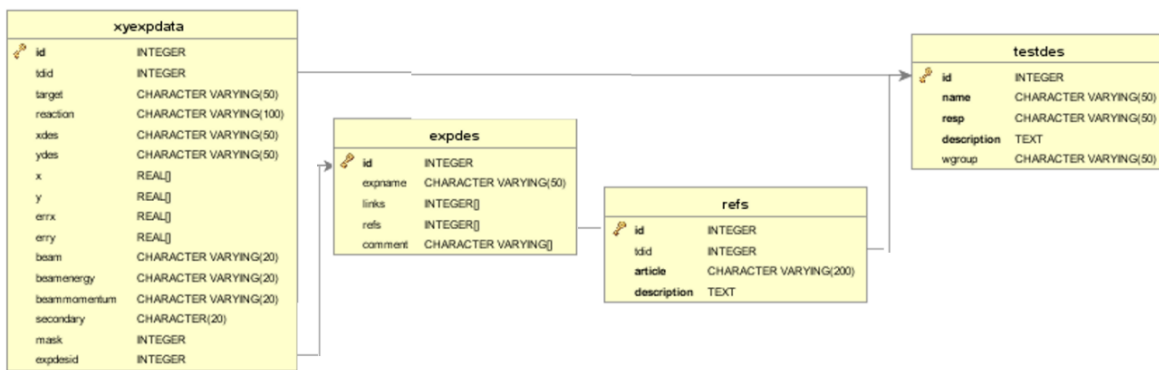

Figure 3: Database Schema

information specific to an experimental data set (i.e. experiment name, experimenters, references, etc.). Results from these experiments (xyexpdata objects) contained a singular reference to an expdes object, linking a plot with distinct experiment information.

In the new expdes objects, I created arrays containing links to default xyexpdata objects to plot. In this way, when an experiment is selected from the experimental data browser, this array of default links is used to present the user with a series of default plots and corresponding selections for parameters. The new, extended database schema is illustrated in Figure 3.

I also added a "Revert to default selections" button for the user to return these default plots—as seen in Figure 4. The user is allowed to make changes to the selections and view different plots as needed, but always has the option to return to a working plot if necessary.
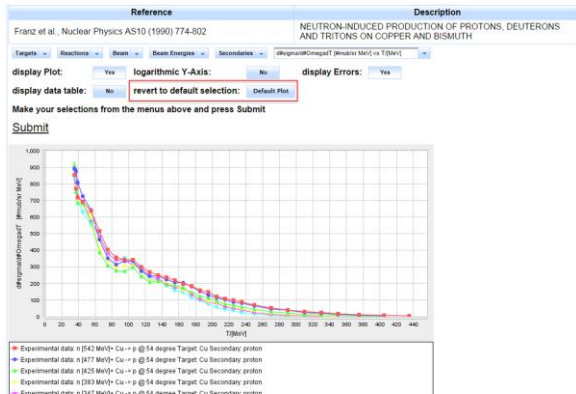

Figure 4: An example of default plot displayed in web application experimental data browser (default button boxed in red)

PION CROSS SECTION SIMULATION

A. Data Generation

In the Geant4 web application test result browser, the user can view data from Geant4 simulation runs. We specifically looked at pion cross sections in matter because of the direct

applications to detector response and measurement results validation to experiments such as LArIAT(Liquid Argon in a Test Beam)[4] at Fermilab, which took data during the summer of 2015 for particle identification, calorimetry, and event reconstruction.

A simple beam-on-target setup was used in Geant4, initializing a target disc of specified thickness with an incident beam of pions at specified energy. Geant4 sets up the simulated experiment according to specified initial parameters and runs at 40 intervals with pion energy range stepping from 50 to 2000 MeV/c. Geant4 runs the beam experiment, keeping count of the number of interactions with the target depending on the type of outgoing particle. I used Python and ROOT scripts to automate data generation over these energy ranges for different materials and different versions of Geant4.

The counting process is done using a sensitive detector approach for a specified target. The incident particle passes through the material, undergoing some sort of interaction. Geant4 recognizes the particle before and after the passage, and must observe the type of interaction in between. Each time a specified type of interaction (i.e. elastic scattering, inelastic reaction, charge exchange, etc.) is observed, it is recorded. The output file keeps the final tally of interactions observed at each energy level, converting them to formal cross section values.

B. Experimental Data Acquisition

Geant4 simulations are compared to experimental data to check their validity. Fortunately, many experiments have documented the cross section behavior of different materials in pion beams. Experiments such as Wilkin [6] and Gelderloos et al. [7] have detailed pion interactions over various energy ranges. These data sets were added into the

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experimental data browser as experimental data for comparison with the new Geant4 pion simulated data.

C. Experimental Data Comparison

As we overlaid the experimental data onto the Geant4 simulated data in Figure 9, we saw agreement of simulation and experiment. In Figures 5, 6, and 7, data for π^+ and π^- have defining characteristics. The delta resonance peak can be observed in each plot at the crests of each plot, indicating delta formation with the nucleons at distinct energy levels.

The peak levels increase with atomic mass; as the number of nucleons present increases, the probability the delta formation will occur at higher energy increases as well. Also, it can be seen the peaks for the π^+ are characteristically lower than the π^- peaks. This is because the incoming π^+ particle interacts via Coulomb force with the positively charged nucleus, resulting in a repulsive force for the π^+ particle and making them less likely to interact. The opposite is true for the π^- particle, so the probability of any interaction with the nucleus such as scattering, inelastic collision is intrinsically higher, resulting in a greater cross section than a π^+ particle.

The cross section also scales proportionally to the atomic mass. Increasing atomic masses produce higher cross sections, as the incoming particle has more nucleons to interact with, resulting in greater reaction probability—and by the same logic, cross section. With this, we expect the cross section to scale like atomic mass^⅔.

In Figure 10, we observed this behavior followed closely with the experimental data from Ashery [9]. The figure takes cross section data at a distinct energy level versus atomic mass. It should be noted that the data was taken close to the delta resonance peaks. A fit estimates the power factor to be around .66.

Geant4 and the data followed this closely, with results hovering around this estimate (.67 and .70, respectively). Geant4's performance seems to hold up against data.

CONCLUSION

The motivation for improvements to the Geant4 validation repository was to maintain the user-friendly interface but still protect the database from malformed inputs and misguided user edits. The Geant4 web application has been updated not only to protect the database against malformed inputs, but also improve user experience with the addition of the default display plots.

We also added new cross section data into the simulated and experimental data repository, focusing mainly on pions. The simulated pion cross section data has also been validated by matching experimental data sets.

REFERENCES

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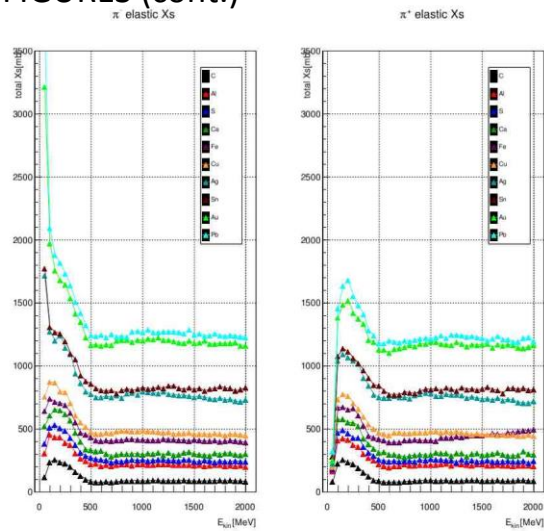
FIGURES (cont.)

Figure 7: Geant4 simulated pion total cross sections in mb as a function of kinetic energy of incident π⁻ (left) and π⁺ (right)

Figure 5: Geant4 simulated pion elastic cross sections in mb as a function of kinetic energy of incident π⁻ (left) and π⁺ (right)
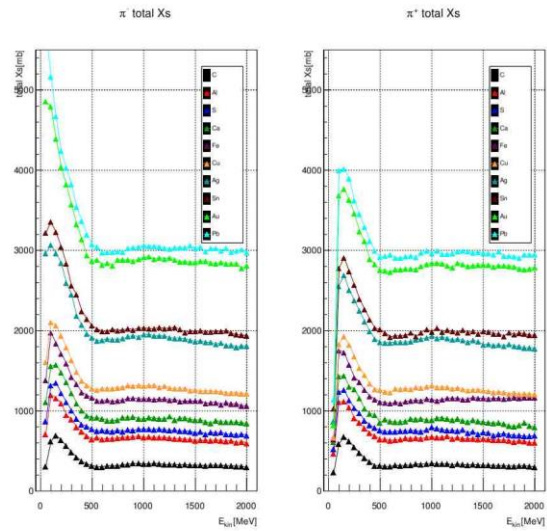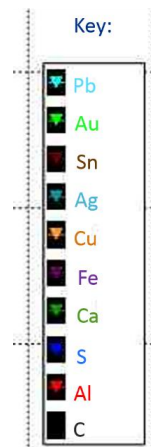

Figure 8: Key for Geant4 pion cross section plots in Figures 5-7

Figure 6: Geant4 simulated pion inelastic cross sections in mb as a function of kinetic energy of incident π⁻ (left) and π⁺ (right)
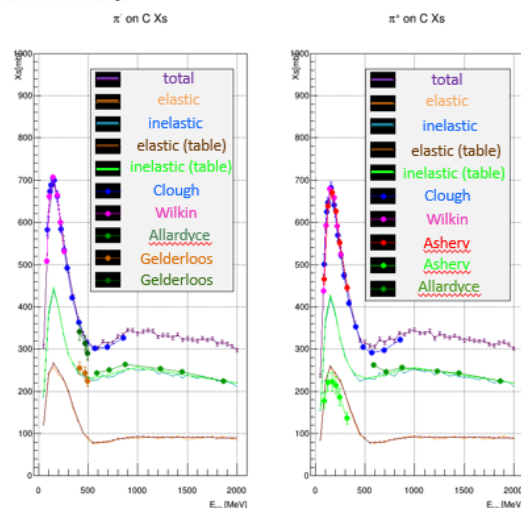

Figure 9: Geant4 simulated pion cross sections on Carbon versus experimental data [5-9]
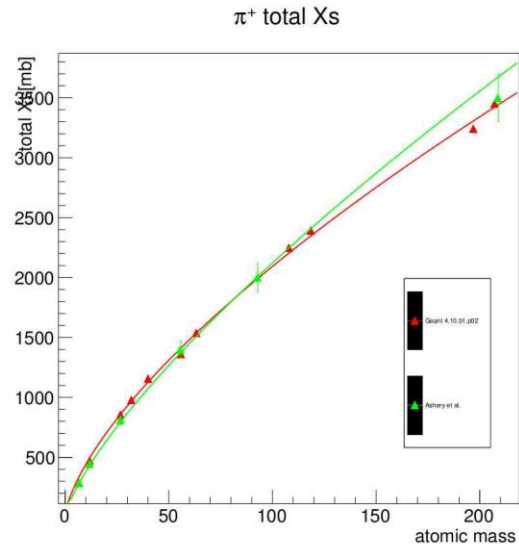
Figure 10: Total pion cross section versus atomic mass (G4 simulated in green and Ashery [9] data in red)