UPDATE ON THE STATUS OF THE FLUKA MONTE CARLO TRANSPORT CODE

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Abstract

The FLUKA Monte Carlo transport code is a well-known simulation tool in High Energy Physics. FLUKA is a dynamic tool in the sense that it is being continually updated and improved by the authors. Here we review the progress achieved in the last year on the physics models. From the point of view of hadronic physics, most of the effort is still in the field of nucleus--nucleus interactions. The currently available version of FLUKA already includes the internal capability to simulate inelastic nuclear interactions beginning with lab kinetic energies of 100 MeV/A up the the highest accessible energies by means of the DPMJET-II.5 event generator to handle the interactions for >5 GeV/A and rQMD for energies below that. At high energies, the new developments concern the embedding of the DPMJET-III generator, representing an improvement with respect to the DPMJET-II structure. This will also allow us to achieve a better consistency between the nucleus-nucleus section with the original FLUKA model for hadron-nucleus collisions. Work is also in progress to implement a third event generator model based on the Master Boltzmann Equation approach, in order to extend the energy capability from 100 MeV/A down to the threshold for these reactions. In addition to these extended physics capabilities, the programs input and scoring capabilities are continually being upgraded. In particular we want to mention the upgrades in the geometry packages, now capable to reaching higher levels of abstraction. Work is also proceeding to provide direct import into ROOT of the FLUKA output files for analysis and to deploy a user-friendly GUI input interface.

Current FLUKA Status

This paper presents an update to the report presented at the CHEP-2003 [1]. The currently available versions of FLUKA include embedded comprehensive heavy ion event generators to simulate nucleus-nucleus inelastic interactions from 100 MeV/A up to energies beyond TeV/A. This capability is provided by a modified version of the rQMD 2.4 code of H. Sorge [2] for inelastic interactions from 100 MeV/A up to 5 GeV/A, and the DPMJET codes [3] for energies above 5 GeV. Versions of FLUKA running DPMJET II.5 have been available for some time and recently a version of FLUKA with DPMJET III has been made available. In addition, photonuclear disintegration has also been added to the inelastic interactions for heavy ions.

This inherent capability to include the complete heavy ion transport physics has allowed FLUKA to be able seamlessly to simulate the space radiation environment. It is clear from efforts to support detailed space applications that such complete integrated treatments of the physics is absolutely necessary to provide the proper evaluation of the complex radiation environment within spacecraft. This is especially true when addressing the task of evaluating the dose related risks to crew members. Simulations that attempt to analyze individual aspects of the environment miss the effects that are due to the combined correlated phenomena. For example, attempting to evaluate the pion fluences without doing a detailed simulation will get the coincident effects wrong as indicated in Figure 1.

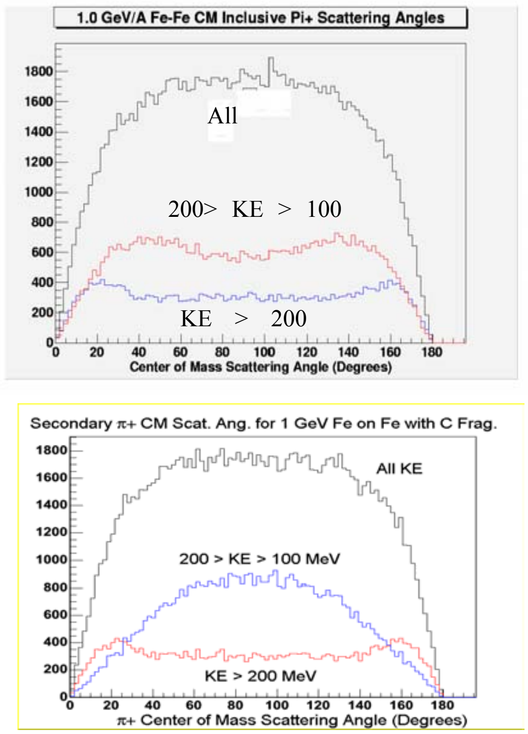

Figure 1. The upper plot displays the inclusive pion Center of Mass scattering angles for several energy bands, and the lower plot displays similar information but only for those events where there is a forward Carbon fragment in the final state. These plote were generated by the rQMD embedded event generator in the current version of FLUKA.

Benchmark comparisons with data have been presented as part of a special session held during the 35th Scientific Assembly of COSPAR, along with a demonstration that it is important to model the details of the experimental setup in which measurements are made along with the effective cuts introduced during the analysis. Figure 2 displays one of the examples shown there to illustrate the differences in the measured results due to different beam conditions with the actual physical setup being employed [4].

Additions have also been implemented in the Geometry input capabilities to allow named volumes in place of the older strict requirement for sequentially numbered volumes. Also, in the combinatorial specification of the physical volumes from the declared primitive elements, logical parentheses can be employed. The geometry input capabilities and the tracking have been modified to accept embedded voxel geometry inputs. At present the embedded voxels must occupy a specified regular parallelepiped within a conventional FLUKA geometry description. In addition, an array containing the material assignments for the voxels must be provided. This embedded voxel input is most useful for including detailed biological geometries such as the well-known Golem [5] voxel human phantom.

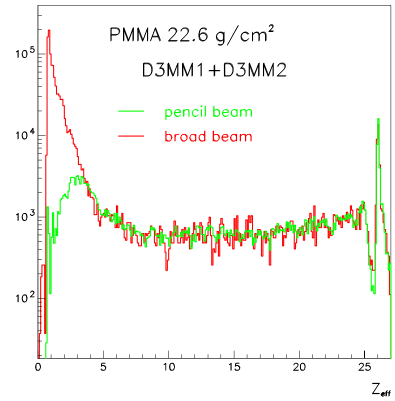

Figure 2. The fragment nuclear charge spectrum is shown for a broad and a pencil beam incident on the central silicon detectors employed by NASA to measure 1.05 GeV/A Fe incident on a 22.6 gm/cm^2 Poly Methylmethacrylate (PMMA) target. The differences are most pronounced for the lightest fragments.

Works In Progress

Under the category of things that are being worked on, first there is the improvement of the heavy ion event generators. The existing solution below 10 GeV/A is unfortunately poorly supplied with data for benchmarking the generators. NASA had recognized this and has embarked on a long term plan to acquire the needed data to insure that the event generators are capable of reproducing the physics across a broad spectrum of projectile-target-energy combinations. As such the FLUKA team is committed to re-examine the event generators continuously and seek updated solutions that offer the maximum likelihood of accurate representations of the real world as far as these reactions are concerned. In an attempt to be proactive several stand-alone event generator projects have been initiated. One effort seeks to follow the strict theoretical rQMD formalism better than is represented by the current code. The other is an initiative from scratch using a Hamiltonian formalism to attempt a more accurate method of handling the relativistic aspects of the collisions. Not only are FLUKA's event generators being challenged continuously, as noted the energy range is being extended down to threshold through the inclusion of a Boltzmann Master Equation (BME) approach.[6] This represents the inelastic reactions accurately for the energy region below 100 MeV/A.

For some time now there has been a commitment to provide FLUKA users with GUI-based tools to address both the "front-end" or the setting up of FLUKA runs and the "back-end" which includes the analysis of the outputs generated by FLUKA. While FLUKA will always provide users with the opportunity to do their own "scoring" FLUKA includes a robust suite of internal scoring capabilities. In the past, there have been various command-line macros along with prescriptions on how to employ them to produce visualizations of these built-in capabilities. This empowers all users to take advantage of these powerful built-in features. A program is underway to provide a ROOT-based GUI tool that includes all of the built-in scoring types. The initial effort has been focussed on the FLUKA fluence scoring associated with the internal "USRBIN" scoring capability.

This effort had progressed to the point where it is possible to examine the interface and anticipate its final form. It includes the ability to select the FLUKA output file directly and it does the conversion of that information into a ROOT file such that it can be viewed and manipulated totally via the GUI interface with fluence plots and GUI-selected profile histograms. These are directly presented without the need to master either ROOT or any command-line capability. On the other hand, the ROOT command-line code produced in the process is user viewable to enable comparison of the details of the needed ROOT C++ commands with the actual outputs in case the user wishes to learn from that example. Figure 3 shows the current GUI tools for this type of analysis.

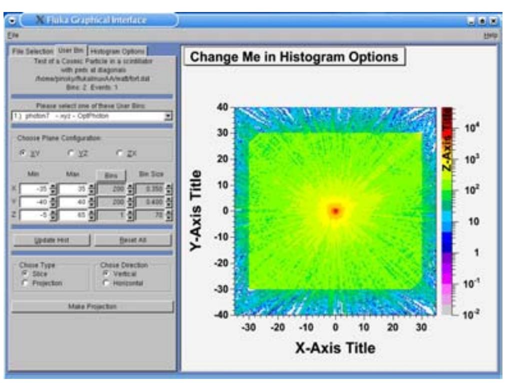

Figure 3. "USRBIN" ROOT-based GUI Interface.

In addition, integrated ROOT-based tools have been developed that encapsulate FLUKA from the initiation of a run through the setting up of a ROOT-based analysis. Initially, this has been accomplished only for a special "Event-Exerciser" version of FLUKA. This application does not include any transport or geometry, but only outputs the final-state particles from the embedded event generators for specific input projectile-target-energy (or momentum) combinations. The output is directly viewable in a ROOT Tree Viewer without the need for the user to become involved in any command-line activity. Figure 4 shows the input interface GUI and Figure 5 shows the resulting Tree Viewer.

Figure 4. Flukaprey "Event-Exerciser" input GUI.

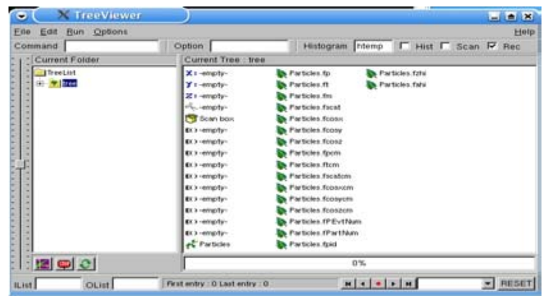

Figure 5. Flukaprey "Event-Exerciser" Tree-Viewer.

For those not familiar with ROOT, Figure 6 shows a typical plot produced directly within the Tree-Viewer. It depicts the inclusive forward (lab KE > 100 MeV/A) charged heavy ion fragment spectrum (for Z>2) produced by the embedded rQMD event generator for 1.0 GeV/A Fe incident on Al that was produced in 10,000 trials.

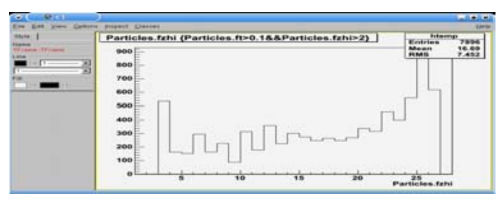

Figure 6. ROOT histogram produced from Tree Viewer.

The current plans are to continue to extend these capabilities to the point where both a GUI tool can be employed to produce the normal FLUKA input file and to launch a FLUKA run. Then upon completion, the user will be able to open another GUI tool to examine and analyse the outputs produced by the standard FLUKA scoring capabilities in a ROOT-based GUI environment.

On the input side, the inputting of the geometry information about a situation remains a singularly complex task. At present the plans for the GUI input tool will require that a specific geometry input file be prepared separately. Over the longer term, plans exist to develop distinct GUI-based tools to facilitate the input of the geometry information.

An agreement has been established between INFN and CERN about the joint future development and support of FLUKA. It includes a provision to make available under proper license the source code of FLUKA free of charge for scientific use.

Some Examples of Recent Biological and Space Applications

One effort that has taken place within the last year is the development of an approach to deal with the transport through micro-porous media such a foam, bone or lung tissue.[7] These micro-porous materials are too fine to allow the detailed representation of their actual microscopic structure, and the typical approximation of replacing the material with some averaging or "homogenization" of the properties does not produce the proper straggling effect on an incident beam emerging from the other side. As an example, Figure 7 depicts the distribution of path lengths in trabecular bone for randomly incident rays. The plot shows the path length distribution in gm/cm^2 per cm of total path length that is in hard bone, the balance being in marrow. The density in hard bone is a factor or two greater that for marrow.

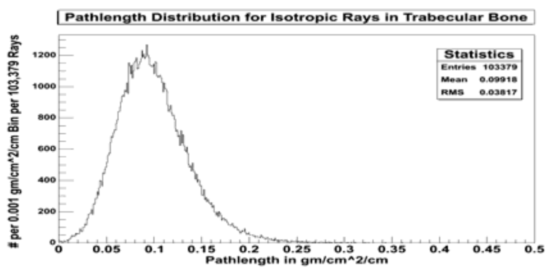

Figure 7. Path length distribution in Trabecular Bone.

To deal with the transport through such materials, the approach is to choose the fraction of the total path length that is on one or the other material individually for each particle that traverses such a medium. The path length fractions are chosen with reference to the global distribution such as in Figure 7.

There has also been a significant effort to employ phantoms to evaluate various dose-related biological endpoints for exposures to space radiation [8]. As an example, Table 1 lists several calculated dose equivalent values for the mathematical phantom known as "Erma" [9] as compared with a similar calculation employing the Golem voxel phantom exposed to the measured flux from the August 1972 Solar Particle Event (SPE) inside several thicknesses of simulated aluminium spacecraft walls.

Al shield *(g/cm^2)*	**Skin**		**Lens**		**BFO**	
	Erma	*Golem*	*Erma*	*Golem*	*Erma*	*Golem*
1	**13.31**	**11.63**	**6.89**	**8.01**	**1.80**	**2.76**
2	**7.25**	**6.57**	**4.90**	**5.81**	**1.32**	**1.95**
5	**2.23**	**2.11**	**1.60**	**1.79**	**0.62**	**0.88**
10	***0.62***	***0.60***	***0.56***	***0.42***	***0.25***	**0.33**

Table 1. Comparison of Calculated Dose Eqs. in Gy-Eq. from the August 1972 SPE with the Mathematical Phantom Erma and the Voxel Phantom Golem for several different Al spacecraft wall thicknesses.

ACKNOWLEDGEMENTS

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