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Performance of the release Geant4.4.1 for simulation of BTeV ECAL Test Beam Data

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Introduction

This is a follow-up of efforts reported in BTeV internal note BTeV-doc-817 [1], which raised several concerns about modeling of electromagnetic and hadronic showers in Lead Tungstate with the Geant4 package [2] in comparison to experimental results [3].

In this write-up we report our understanding of the current status of some of the relevant aspects of the package, as of release Geant4.4.1, including patch01 (July 28, 2002).

The goal at this point is to look quickly at several changes and updates in the release Geant4.4.1, NOT a detailed analysis of the current status of the Geant4 package as a whole. The emphasis remains on modeling interactions of hadrons with matter.

Chapter 1

Geometry, Beam, Physics List, and Run Conditions

To check on modeling the BTeV/ECAL test beam setup exposed with either e^- or π^- beam, a matrix of 5x5 Lead Tungstate ($PbWO_4$) crystals was used. The $PbWO_4$ density was $8.28g/cm^3$. Each crystal was 2.7x2.7x22cm^3 and wrapped in $80\mu k$ of Teflon (chemical formula C_2F_4, density $2.20g/cm^3$).

The Physics List from the Geant4 example novice/N04 was used, as in the previous test [1]. It is our understanding that its hadronic part corresponds to the C++ re-write of the Gheisha [4] code within the Geant4 framework.

A point-like beam was parallel to the z-axis and was incident on the xy-center of the central crystal.

When modeling electromagnetic showers with Geant4, our major concern was the speed of the package, not its physics performance which was found reasonable in our previous test. Because of that, it was decided to run only a test with 10GeV e^-, along with the similar application based on Geant3 [5], to see if the speed had improved. No BTeV-specific apparatus functions, such as photostatistics variations or non-uniformity of light output along crystal, were taken into acount.

To check the fixes of the azymuth asymmetry in the hadronic showers induced by high energy pions, it was decided to use only the two-dimensional distribution of energy deposition by a 40GeV $\pi-$ in the 5x5 matrix of crystals.

A production cut of $1mm$ was selected for all particles. In addition, a tracing cut of 1MeV was selected for all particles. This is a sensible compromise between precision and speed when modeling electromagnetic showers and should be reasonable to address the Geant4 speed issue. This should also be good enough to simulate hadronic showers with reasonable accuracy. Control jobs were run for π^+ and $\bar{p}$ without tracing cuts; the output was statistically similar to that with the 1MeV tracing cut.

A beam of 40GeV π^- was parallel to the z-axis and was incident within $\pm 9mm$ of the xy-center of the $PbWO_4$ box, to reflect the test beam spread.

To check on indications of possible energy non-conservation in the Geant4, a large box-shaped piece of $PbWO_4$ was used. The size of the box was 1x1x1.5m^3. It was placed inside a mother volume made of Air.

The particles were π^+, π^-, p, $\bar{p}$, each of 2GeV kinetic energy, normal incidence at the center of the box.

We collected 5,000 events for each sample except for the case of modeling hadronic showers induced by 40GeV π^- in the matrix of $PbWO_4$ - for which a sample of 25,000 events was simulated.

For more detailed descriptions and/or motivations see BTeV-doc-817 note [1].

Chapter 2

Simulation of Showers

2.1 Simulation of Electromagnetic Showers

No changes in Geant4.4.1 have been noticed when modeling electromagnetic showers induced by 10GeV e^- in this particlular configuration. The speed of the packages remains somewhat of concern, compared to Geant3. Moreover, more concerns about the speed came up during this test.

The original test of the electromagnetic subpackage of Geant4 was done with the Physics List which contained only γ's and leptons ($e^\pm$, $\mu^\pm$, and the corresponding neutrinos) and the electromagnetic processes.

The latest modeling of the showers induced by a 10GeV e^- was done with the Physics List which, in addition to the electromagnetic physics, contained also hadronic physics, even if that part should not be involved in simulation of purely electromagnetic showers.

It turned out that with the full Physics List the amount of CPU needed to model electromagnetic showers is about 1.5 time more comparing to the List containing electromagnetic processes only. The output in terms of energy deposition is **exactly** the same.

This is likely to indicate that the speed of the Geant4 package depends on the length of the Physics List (which is a technical matter of the code implementation); it brings the speed factor to about 4-4.5 in favor of the Geant3 package.

While the speed is not the only aspect of a simulation package, it is still an important issue, especially when processing millions of complex events to model a full scale detector response.

It should be stressed that in the Physics List used in the latest test came from example supplied with the Geant4 package.

Also, while there are many way to optimize the Geant4-based application (as well any other software) for a particular task, the general simulation goal of a High Energy Physics project is to model the detector response to a variety of particles in every sigle event. Thus, testing the Geant4 performance with the complete Physics List is a reasonable thing to do.

It will be very beneficial if the Geant4 team eventually pays more attention to this issue.

2.2 Simulation of Hadronic Showers

The simulation of hadronic showers with the Geant4-Gheisha code, release 4.1, has produced more reasonable picture in comparison to the one of the release 4.0.

The lateral distribution of the energy deposited by a hadronic shower induced by 40GeV π^- seems symmetric now. It looks like the bug introduced in earlier version(s) has been fixed.

The modeling of the energy deposition by π^+, π^-, p, $\bar{p}$ of the kinetic energy of 2GeV can be illustrated with fig.2.1. The spectra now lay within the right limits.

However, we would like to stress that the conclusion whether the modeling is done absolutely right can only be drawn by comparing simulations to a variety of experimental results in a wide range of beam types and energies. And we don't have this luxury since our data set taken with a beam of a particular type and energy, and the geometry of our prototype has limitations.

We would like also to point out the importance of releasing patch01 in addition to Geant4.4.1 (the fixes are now automatically included into the distributed release). However, an attemp to model hadronic showers with the initial release Geant4.4.1 still raised concerns. The pion-induced showers in $PbWO_4$ still indicated energy non-conservation. The showers induced in $PbWO_4$ by a $\bar{p}$ of 2GeV momentum (about 1.27GeV kinetic energy) resulted in the energy deposition spectrum of somewhat strange profile (fig.2.2, right, black line). The fixes in the patch01 not only affect modeling of showers induced by pions but also seem to shift energy deposition spectra by p and $\bar{p}$ closer to the right position; the case of $\bar{p}$ of 2GeV kinetic energy is shown in fig.2.2,left (compare red and black lines). Energy deposition spectrum for $\bar{p}$ of 2GeV momentum looks more reasonable, too (fig.2.2, right, red line).

The simulated energy deposition by 40GeV π^- in the 3x3 matrix of $PbWO_4$ crystals, which were 22cm deep, seems slightly affected as well. The profile of the simulated energy deposition spectrum in the 3x3 matrix becomes closer to the experimental one, as shown in the fig.2.3, where the blue line represents experimental data, the black line represents result of simulation with Geant4.4.0, and the red line is for results simulated with Gean4.4.1+patch01. It is clear that simulating more events will be better but 25,000 events is a reasonable compromise, given limited time.

However, comparison of the experimental energy deposition in the central crystal and in the surrounding 8 crystals vs simulation indicate discrepancies, as shown in fig.2.4 and fig.2.5; the transverse profile of the hadronic shower simulated with the Geant4-Gheisha remains narrow in comparison to the experimental data (see Table 1)

Table 1.

TB (GeV)	$E_9^{exp} = 7.5 \pm 0.7$	$E_1^{exp} = 4.4 \pm 0.5$	$E_8^{exp} = 3.1 \pm 0.4$
G4.4.0	$E_9 = 6.9$	$E_1 = 5.1$	$E_8 = 1.8$
G4.4.1	$E_9 = 7.2$	$E_1 = 5.0$	$E_8 = 2.2$
		E_1/E_1^{exp}	E_8/E_8^{exp}
G4.4.0		1.16	0.58
G4.4.1		1.13	0.70

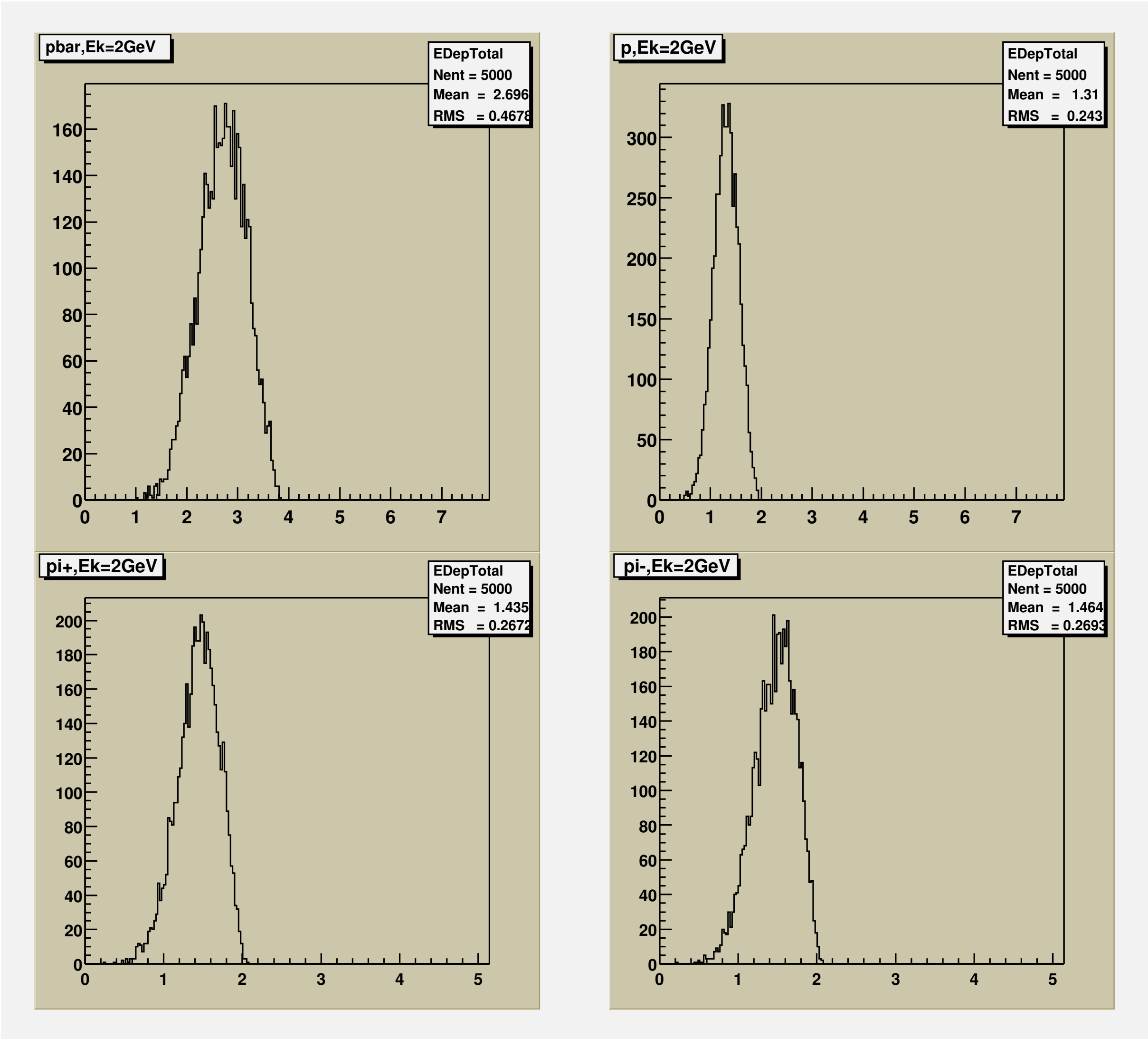

Figure 2.1: Energy deposition spectra for $\bar{p}$, p, π^+, and π^- of E_k=2GeV

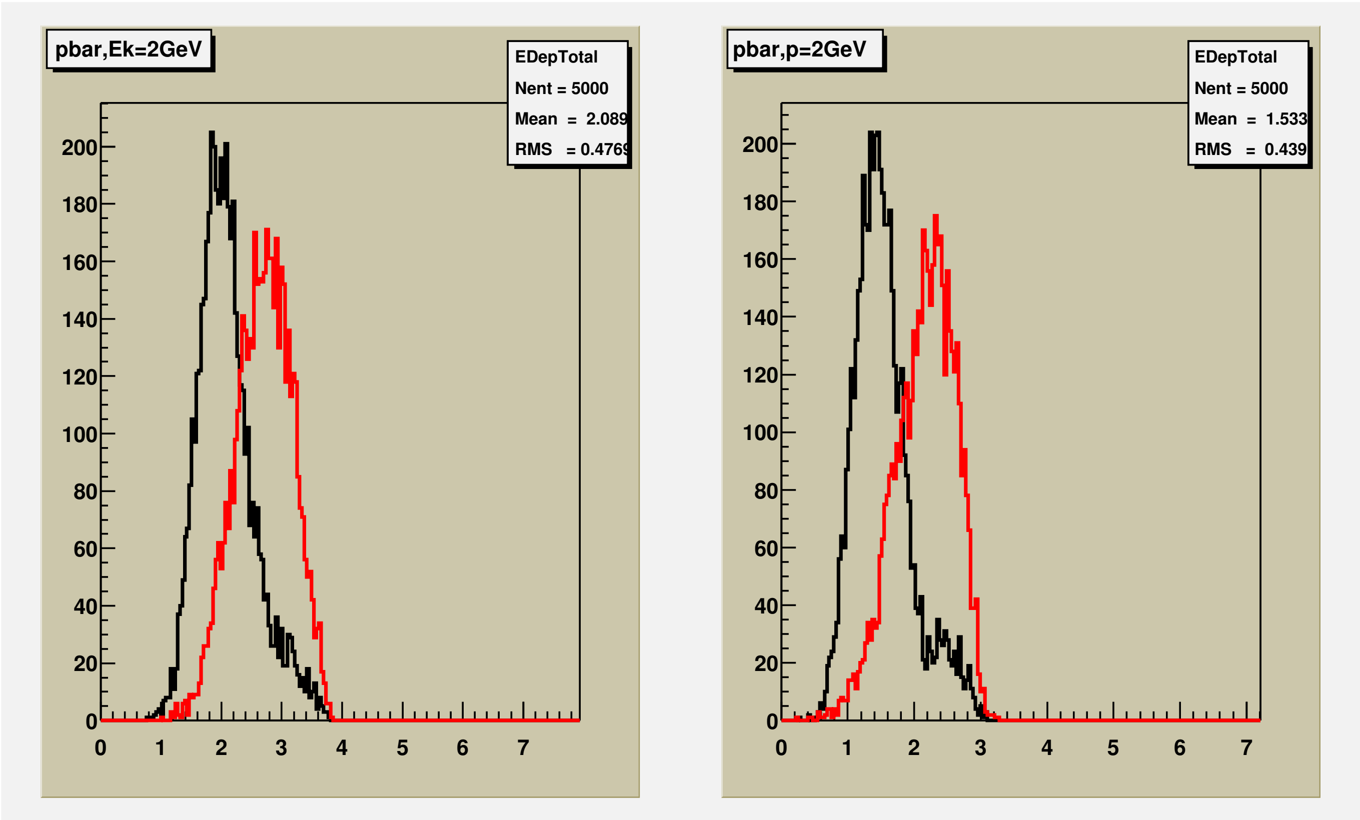

Figure 2.2: Energy deposition spectra for $\bar{p}$ of E_k=2GeV and p=2GeV, before (black) and after (red) fixes released in patch01

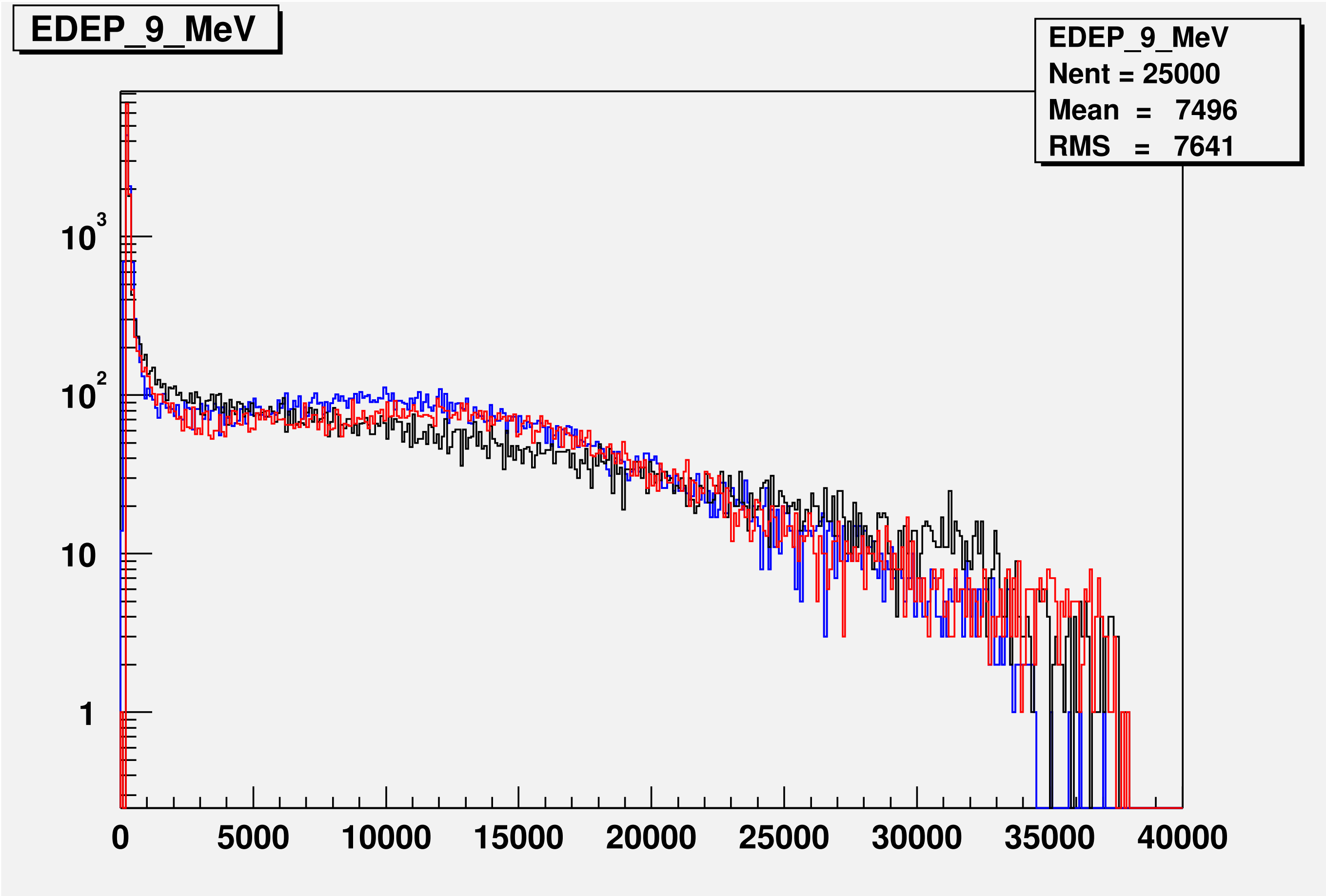

Figure 2.3: Energy deposition in 3x3 matrix of $PbWO_4$ crystals by π^- of p=40GeV (blue) compared vs Geant4.4.0 (black) and Geant4.4.1 (red) simulation

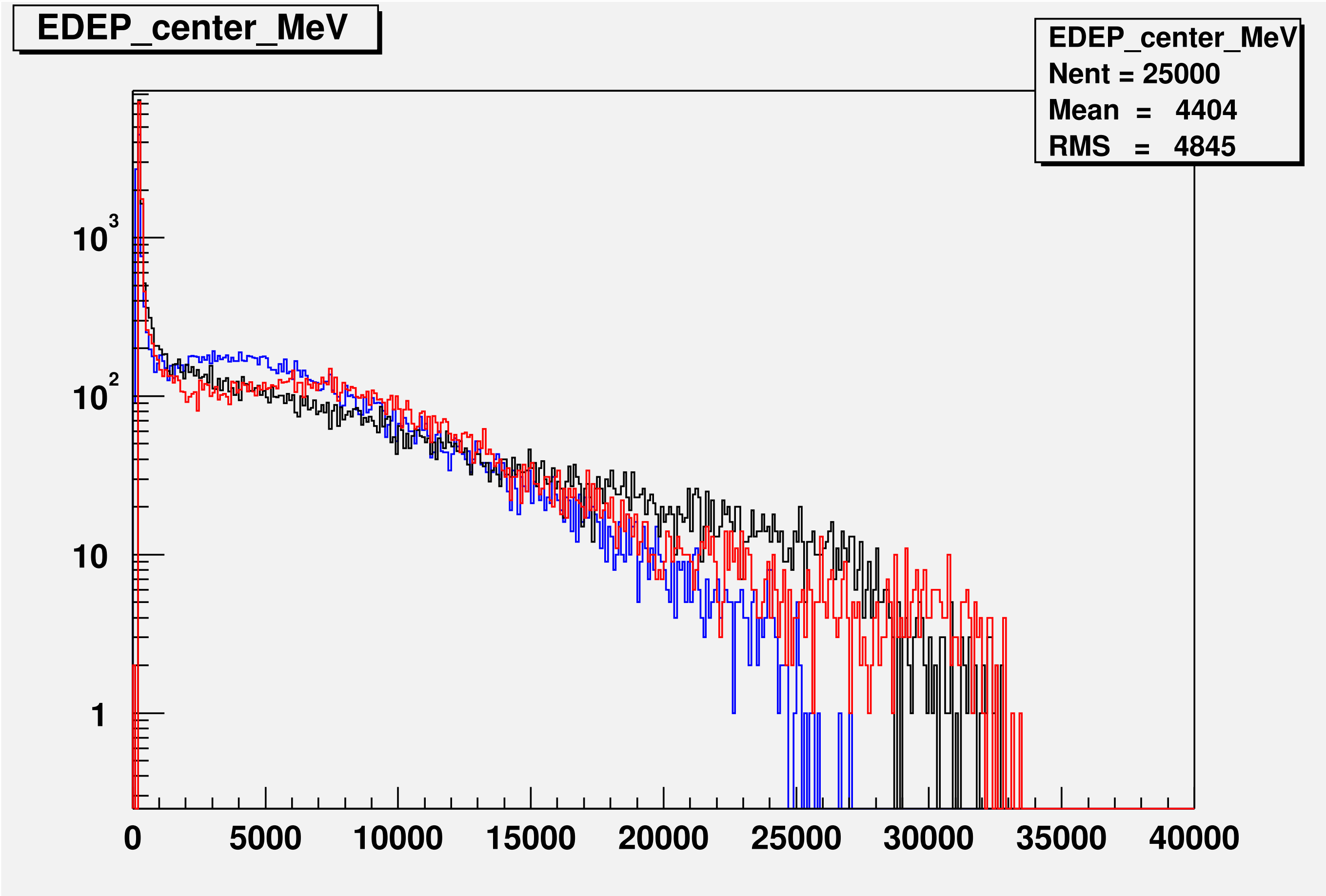

Figure 2.4: Energy deposition in the central $PbWO_4$ crystal by π^- of p=40GeV (blue) compared vs Geant4.4.0 (black) and Geant4.4.1 (red) simulation

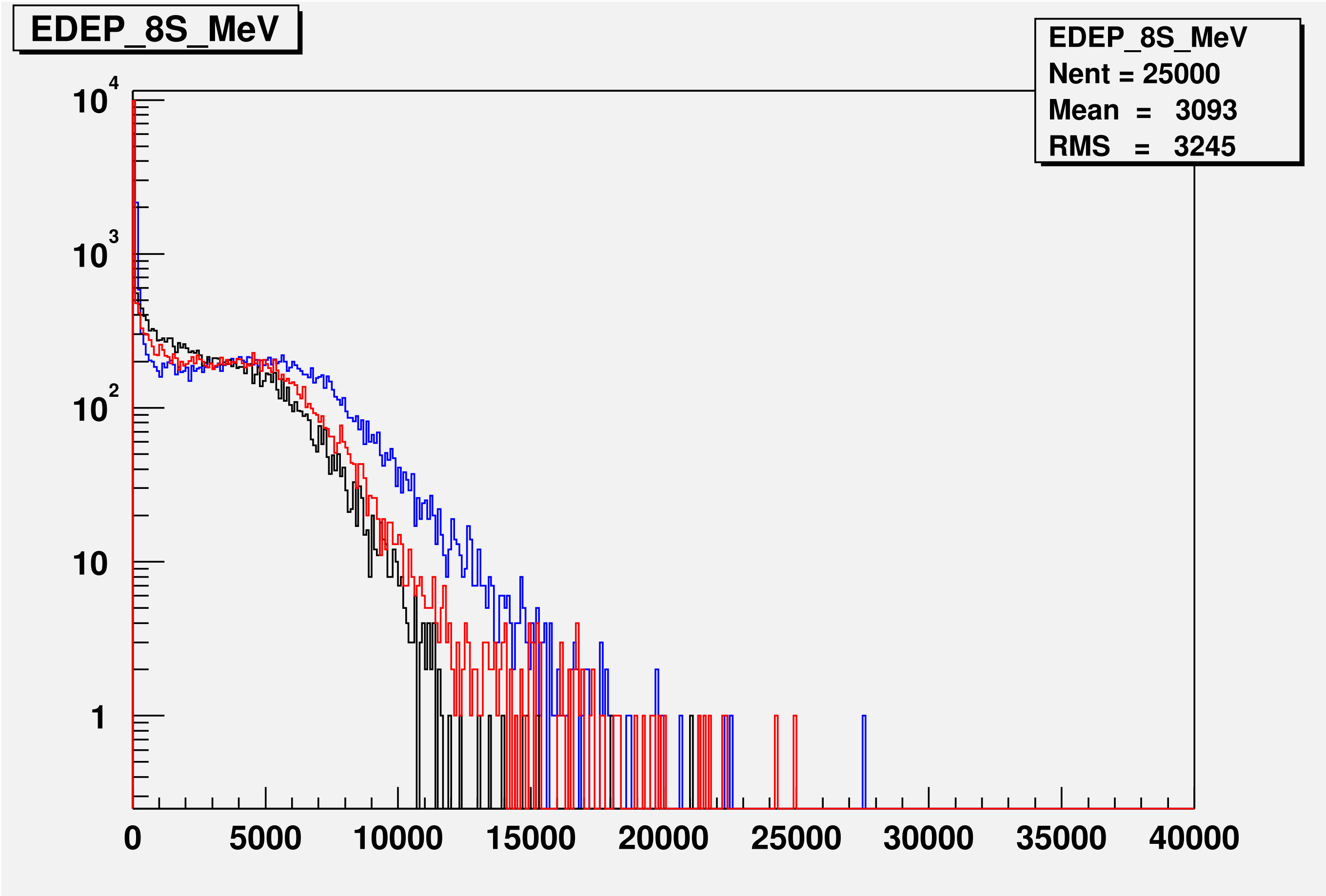

Figure 2.5: Energy deposition in the 8 $PbWO_4$ crystal around central crystal by π^- of p=40GeV (blue) compared vs Geant4.4.0 (black) and Geant4.4.1 (red) simulation

Conclusions

We appreciate the fact that the Geant4 team has taken into account the concerns that were important to BTeV and has fixed several important bugs in the package.

We point out that this particular test is only a small part of evaluation work and has its limitations. It addresses only simulation of calorimetry. It doesn't employ a variety of options in Geant4, especially when modeling interactions of hadrons with matter. Refining of experimental results is also an ongoing process.

We would also like to stress that comparison vs experimental data of various types is a very important part of validation of any simulation package, including Geant4.

It will be interesting to collect more information about the Geant4 performance, when empoying other physics models, how it compares vs experimental results. We would really appreciate if the Geant4 team collects more references about activities and experiences of this kind, both positive or negative, in other HEP projects, as it will likely reduce work duplications.

We would appreciate suggsetions from the Geant4 team about more sophisticated use of Geant4.

We remain concerned about the speed of the package in comparison to its preceeder Geant3; we hope that eventually the Geant4 team will pay more attention to this important characteristics of any software package.

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