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NA2 VALSIM Task Status 2006 EUDET-Memo

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Abstract

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1 Introduction

The VALSIM project's goals are derived from the simulation requirements for the prototype calorimeters - which have fine-grained sampling structure. As a result the accuracy of the detailed detector simulation is critical for the physics performance of the calorimeter. The accurate simulation of hadronic interactions is very important, and in particular the lateral shower distribution.

Recent test beam measurements have raised issues regarding the simulation of the hadronic shower shape. Thus the main current tasks of NA2 VALSIM Task in 2006 have been investigating the origin of disrepancies observed in the shower profile in experiment test beams[2], verifying the hadronic process cross sections, benchmarking neutron production, transport and interactions.

In addition to accurate shower shapes, both longitudinal and lateral, the simulation engine must also simulate well the ratio of energy deposited by electromagnetic and hadronic projectiles (the e/π ratio), and the deviations from linearity seen in the energy deposited. the agreement seen for these quantities in test beams must also be maintained, and potentially improved.

We report on studies of Geant4 [1] illuminating shower development in setups similar to recent test beam setups, on a review of hadronic cross sections and the benchmarking of neutrons using the TARC experiment.

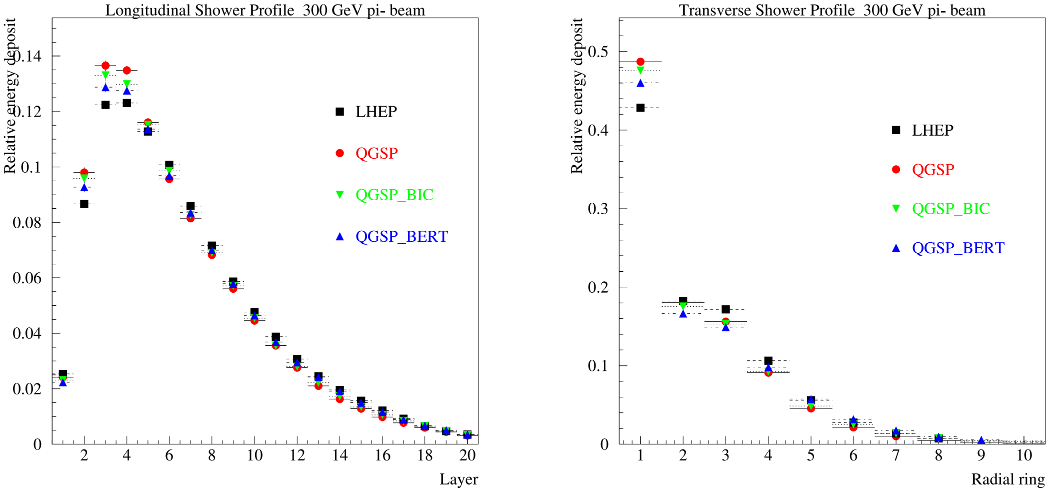
2 Hadronic Shower Shapes

Recent studies have reported disrepancies between the shower profile simulated with the Geant4 physics lists LHEP and QGSP, and that measured in test beam studies [2, 3]. We note that better agreement for the longditudinal profile was seen between the LHEP physics list and data, than for QGSP.

A key goal of present work is to identify the impact of the various physics processes on the development of hadronic showers, in order to improve the longitudinal (and lateral) shower profiles. We use two complementary approaches:

1. verification: compare physics models with thin-target data, checking in particular elastic scattering, neutron production and scattering, hadron inelastic cross-sections, multiplicity and spectra,
2. investigation: measure the different components in the shower evolution, and compare between physics lists, and with qualitative expectations, to identify the source(s) of disrepancies. This involves monitoring observables in simplified calorimeter setups and comparing results with different physics lists/configurations.

Sample results of the second approach are shown below. Fig. 1 shows normalized longitudinal (a) and radial (b) shower profile for 300 GeV π^- on a simplified Copper, liquid Argon calorimeter (similar to ATLAS HEC[3]), for different Geant4 physics list options ('engines'). Each layer is half a radiation length long. The clear differences in the



(a) (b)

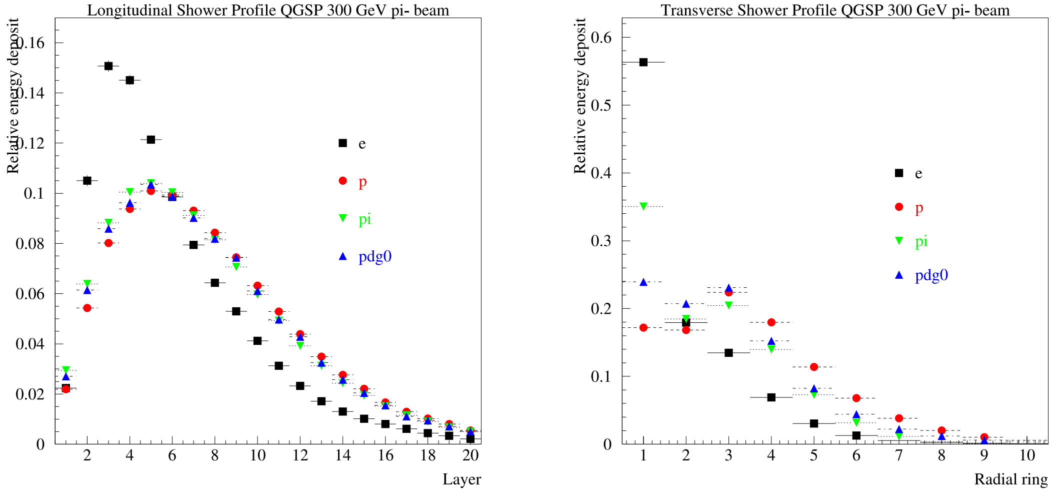
Figure 1: Normalized longitudinal (a) and radial (b) shower profile for 300 GeV π^- on a simplified ATLAS HEC (Cu-LAr) calorimeter, for different Geant4 physics lists.

shower shapes of these physics list 'engines' is visible.

To investigate the origin of these differences, we have studied the contribution of different particles to visible energy deposition. The contributions of different particle types to the visible energy for LHEP and QGSP physics lists, for incident π^- at 30 GeV, 100 GeV, and 300 GeV in the same simple Cu-LAr calorimeter are as follows: electrons give the dominant contribution (60-80%), followed by protons (10-18%), then pions (7-12%) and finally neutrons and nuclei (4-8%). There is a clear excess observed in the energy deposited by electrons in the QGSP physics list. The origin of this is the larger fraction of π^0s produced in high energy interactions.
Each particle provides different longitudinal distributions in terms of shower shape. Fig. 2(a) shows normalized longitudinal shower profile for 300 GeV π^- for different particle types, for the QGSP physics list. Normalized radial shower profiles for 300 GeV π^- on the simple Cu-LAr calorimeter, for different particle types, with the QGSP physics list are shown in Fig. 2(b).

3 Integral Hadronic Cross-Sections

The integral cross-sections for hadronic interactions plays an important role in correct simulation. Verifying the total cross-section and the integral elastic and inelastic cross sections for interaction on different targets is thus important. This verification has been one of the VALSIM tasks during 2006.
Comparisons have been undertaken for protons, neutrons, π^+ and π^- on C, Fe, Cu, W,



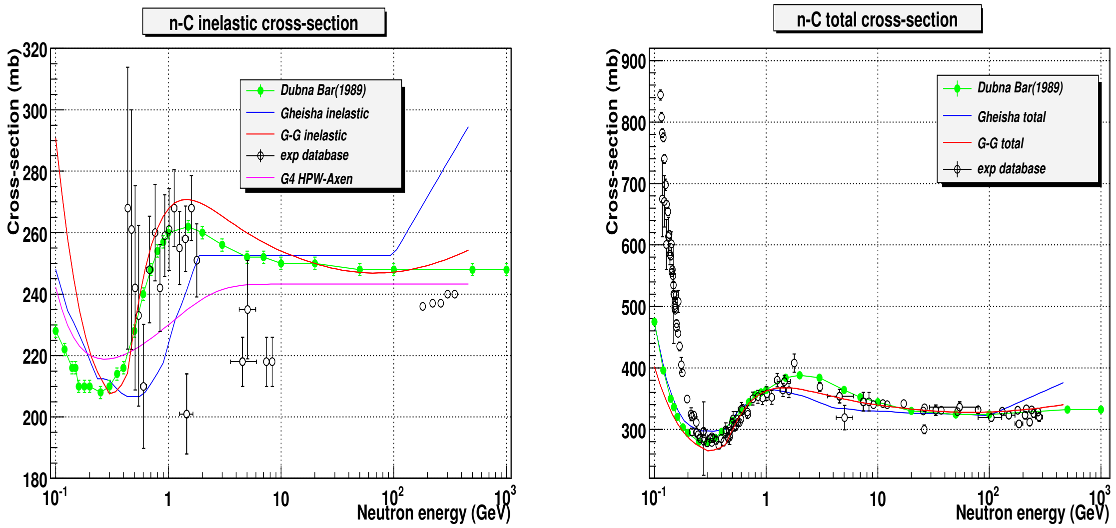
(a) (b)

Figure 2: Normalized longitudinal (a) and radial (b) shower profile for 300 GeV π^- on a simplified ATLAS HEC (Cu-LAr) calorimeter, for different particle types, with QGSP physics list.

Pb, and U targets in the particle energy range $0.1 - 1000 GeV$. One limitations identified of existing Geant4 cross sections was the dependence of integral cross-sections on energy in the range $>$ 100 GeV. Existing implementations had a large relativistic rise (GHEISHA) or were constant above 100 GeV, from low energy optical models [7]. A new cross section implementation for total and inelastic hadron integral cross sections was developed, to correct this. It utilizes a simplified version of the Glauber model with Gribov correction (GG model). Fig. 3(a) and Fig. 3(b) demonstrate the comparisons, and the new 'GG' model, in the integral inelastic and total cross sections of neutrons on carbon target, respectively. At energies above 1 GeV agreement is found with experimental data [6] at a typical level of $10 - 20\%$. The expected small relativistic rise versus energy for the range $>$ 100 GeV is reproduced in the 'GG' model. An additional implementation of integral cross sections for protons using Barashenkov's evaluations [7] has been initiated, to account for the low-energy behaviour, below 1 GeV.

4 Neutron Transport TARC Benchmark

A neutron transport benchmark was studied in order to further the validation of neutrons in Geant4 . The TARC (neutron driven nuclear Transmutation by Adiabatic Resonance Crossing) experiment took data between 1996 and 1997 at CERN.
Protons of momentum 2.5 GeV/c and 3.5 GeV/c were incident on a large lead target. It is roughly cylindrical with a diameter of 3.3m and length 3m, comprising 334 tons of lead. The beam was stopped 30cm before the center of the target, giving an interaction shower approximately centered in the volume.



(a) (b)

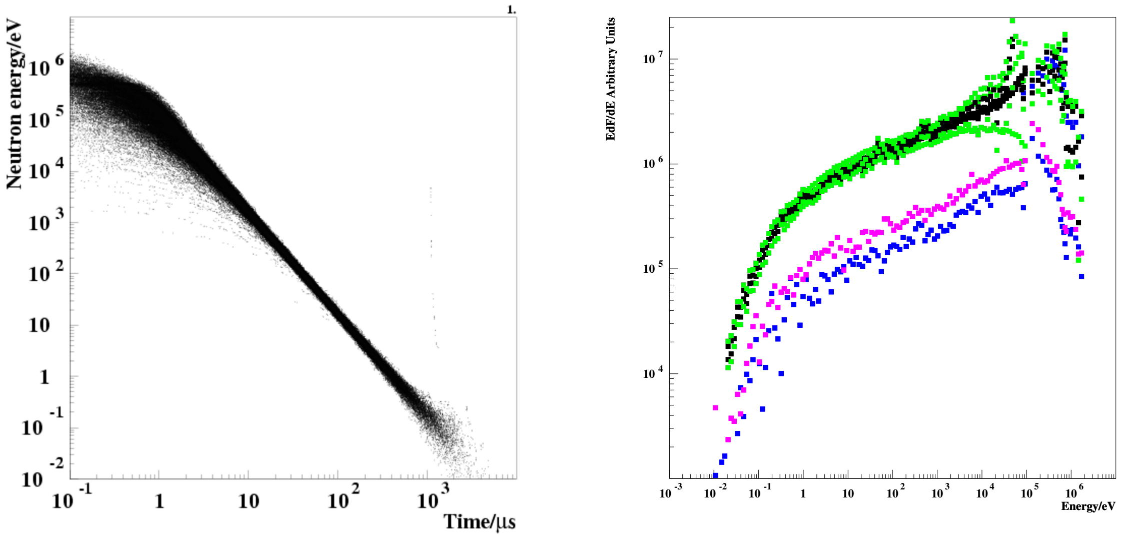
Figure 3: Integral inelastic (a) and total (b) cross-sections of neutrons on carbon target. Experimental data (open points) from [6], lines correspond to different GEANT4 models, closed points are Barashenkov parametrization [7].

The binary cascade physics model is used for proton interactions, along with the neutron HP model for the interaction, transportation, scattering and capture of neutrons below 20 MeV.

Due to the lead purity and the large elastic cross section the energy of a neutron is correlated with its time of measurement. Measurements in TARC confirmed this. This simulation tests neutron transport in GEANT4 using the Neutron HP model.

A plot of the time (μs) vs. energy (eV) for neutrons produced from 2.5 GeV/c protons using the Bertini cascade is shown in Fig. 4(a). Between 1μs and 1 ms a clear correlation can be seen with quite narrow distribution. The quasi-Gaussian was fitted over a reduced range to give the mean values of 168.6 and 167.2 for the binary and Bertini models respectively. The TARC experiment measured the correlation to be 173$\pm$2 using resonance capture with eight different isotopes across the energy range 4.28-337 eV.

The neutron fluence was measured and simulated at a radius of 45.6 cm from the centre of the geometry. It is shown in Fig. 4(b) for protons of momentum 2.5 GeV/c, plotted as a function of neutron energy from 0.01 eV up to 2 MeV. The energy bins were chosen to match those of the experimental data which are plotted in black. The green data points correspond to the ± combined statistical and systematic error of the experiment. The simulation data are plotted for the Bertini (magenta) and binary (blue) cascades. The spectral shape is in good agreement between GEANT4 and the TARC data but there is a clear shift in the normalisation between the two. A potential cause under investigation is a reduced number of neutrons produced from the cascade and pre-compound models in GEANT4 .



(a) (b)

Figure 4: Neutron time-energy correlation using the Bertini cascade (a) and fluence measured and simualted at 45.6 cm (b).

5 Summary of General Issues

Shower shape simulations have confirmed the source of differences observed between physics lists, and identified a potential cause of the difference with test beam longditudinal shower shower profile. A comparison of nucleon and pion cross sections for key elements has been undertaken. Confirmation of the spectrum from neutron transport, and differences in the neutron flux have been observed in the comparison with TARC experiment data.

Further verification against thin-target data is planned, in particular for π^0 and neutron production, and for projectiles in the region $3 - 20$ GeV, to address issues identified.

Acknowledgement

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