Geant4 Hadronic Validation Efforts at FNAL

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Outline

- Validation with Published data
  - Data Set
  - Data Quality
  - First Comparisons
- Documentation
- Summary and Outlook

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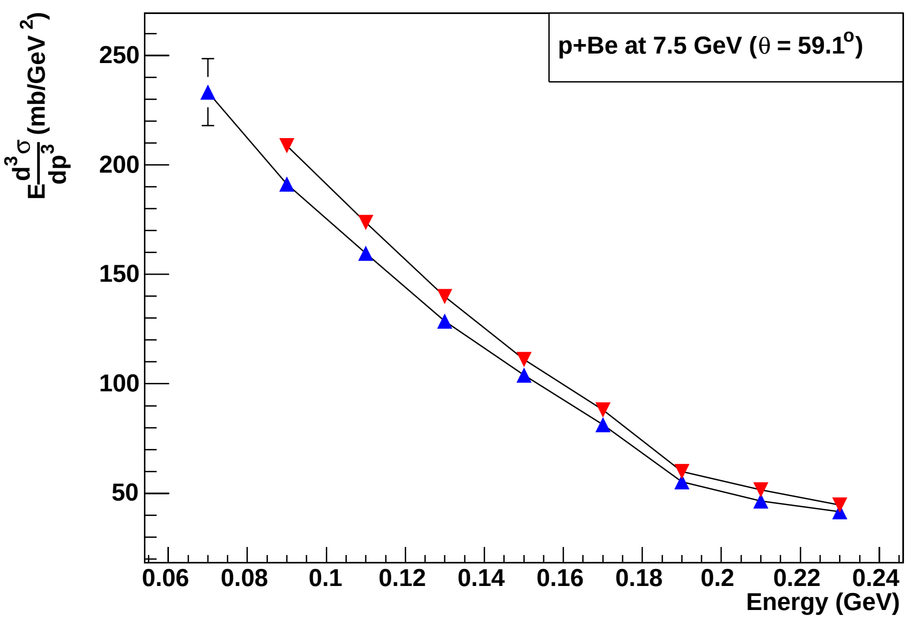
Data Set

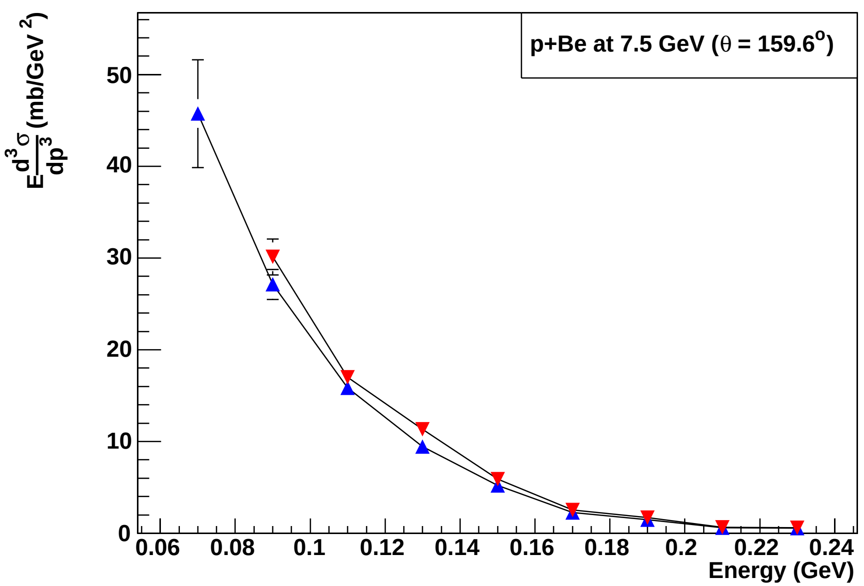
Data Set from ITEP (Yu. D. Bayukov *et.al*., Preprint ITEP-148-1983, Sov. J. Nuclear Physics **42**, 116)

- Nuclear Scan: Inclusive proton production at 4 different angles in 8-9 kinetic energy bins in proton-nucleus collision (12 targets from Be to U) with 7.5 GeV/c proton beam
- Angular Scan: Inclusive proton production at 29 different angles in 8-9 kinetic energy bins on p-nucleus or π^--nucleus targets (4 targets from C to U) with 7.5 (5.0) GeV/c p (π^-) beam
- Energy Scan: Inclusive proton production at 4 different angles in 8-9 kinetic energy bins in p/π^+/π^--nucleus collisions (4 targets from C to U) with 11/7/3 beam momenta between 1 and 9 GeV/c

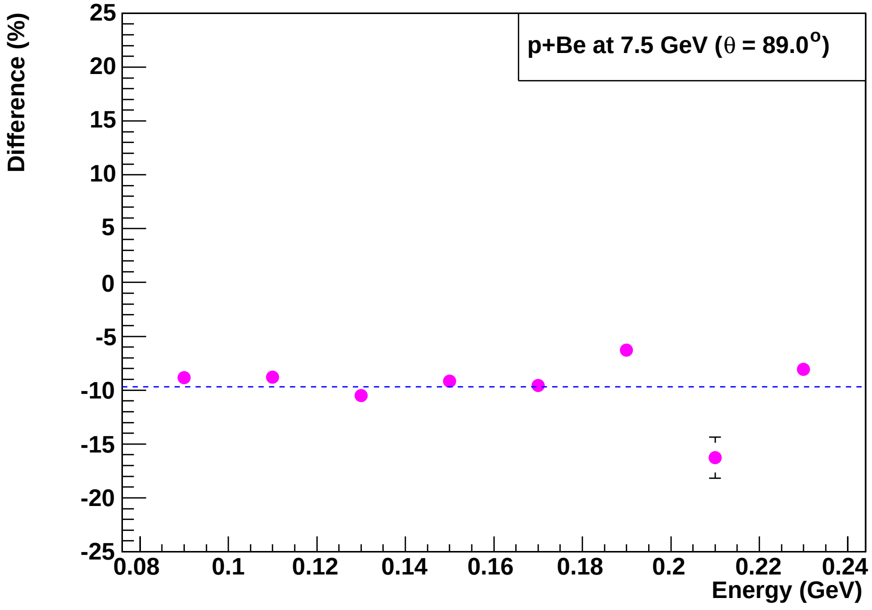
Data Quality (I)

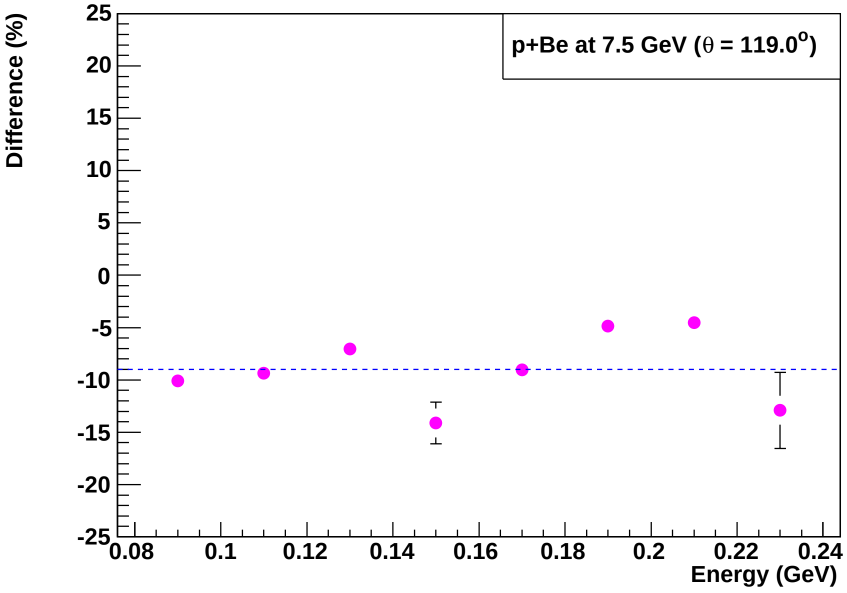
- Quantities measured are Lorentz invariant differential cross sections
- Statistical uncertainty are between 1-10%
- Systematic uncertainty quoted are between 5-6%
- However the same differential cross section table sometimes appear from two sets of measurements





Data Quality (II)





- Mean difference between the 2 sets of data points are typically 10% or smaller
- Overall normalization uncertainty could be ~15%

Comparisons

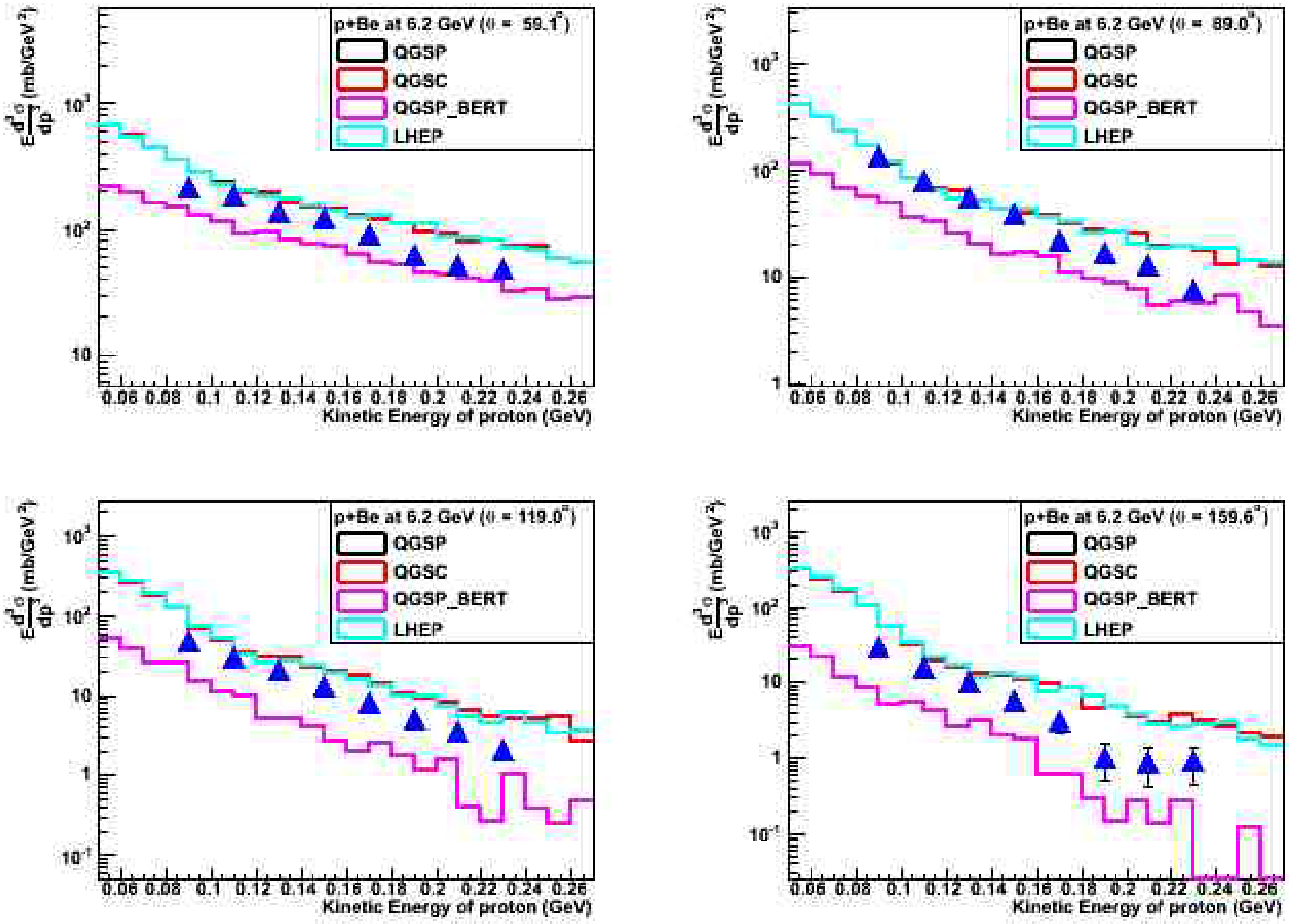
Method of Comparison:

- Use a standalone code initiating one physics model with particles of a fixed momentum and look at number of interactions and the products
- Use a specific test code (test30) in Geant4 application
- Alternately we can take a standard physics list and verify by standard simulation process

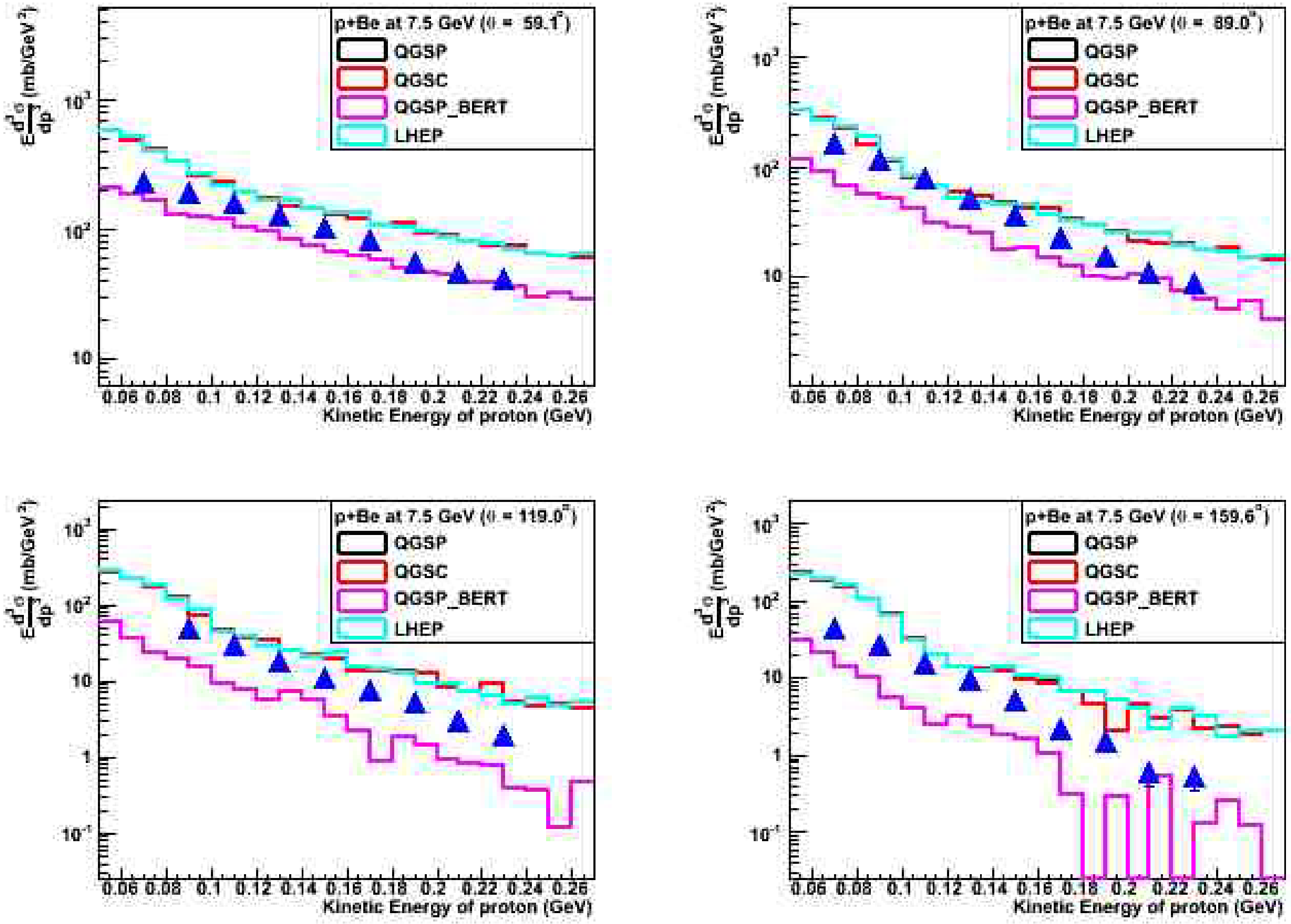
Develop a tool within CMSSW Framework:

- Look into PostStepPoint's for any hadronic process (can be used as a Watcher of G4Step or as a UserSteppingAction)
- Looks at the list of secondaries produced (optionally saves the 3-momenta, mass of all produced particles, process ID for the interaction)
- Kill secondaries as well as the primary track after the first interaction
- Create a simple geometry with one material and look at collision product for a fixed beam energy

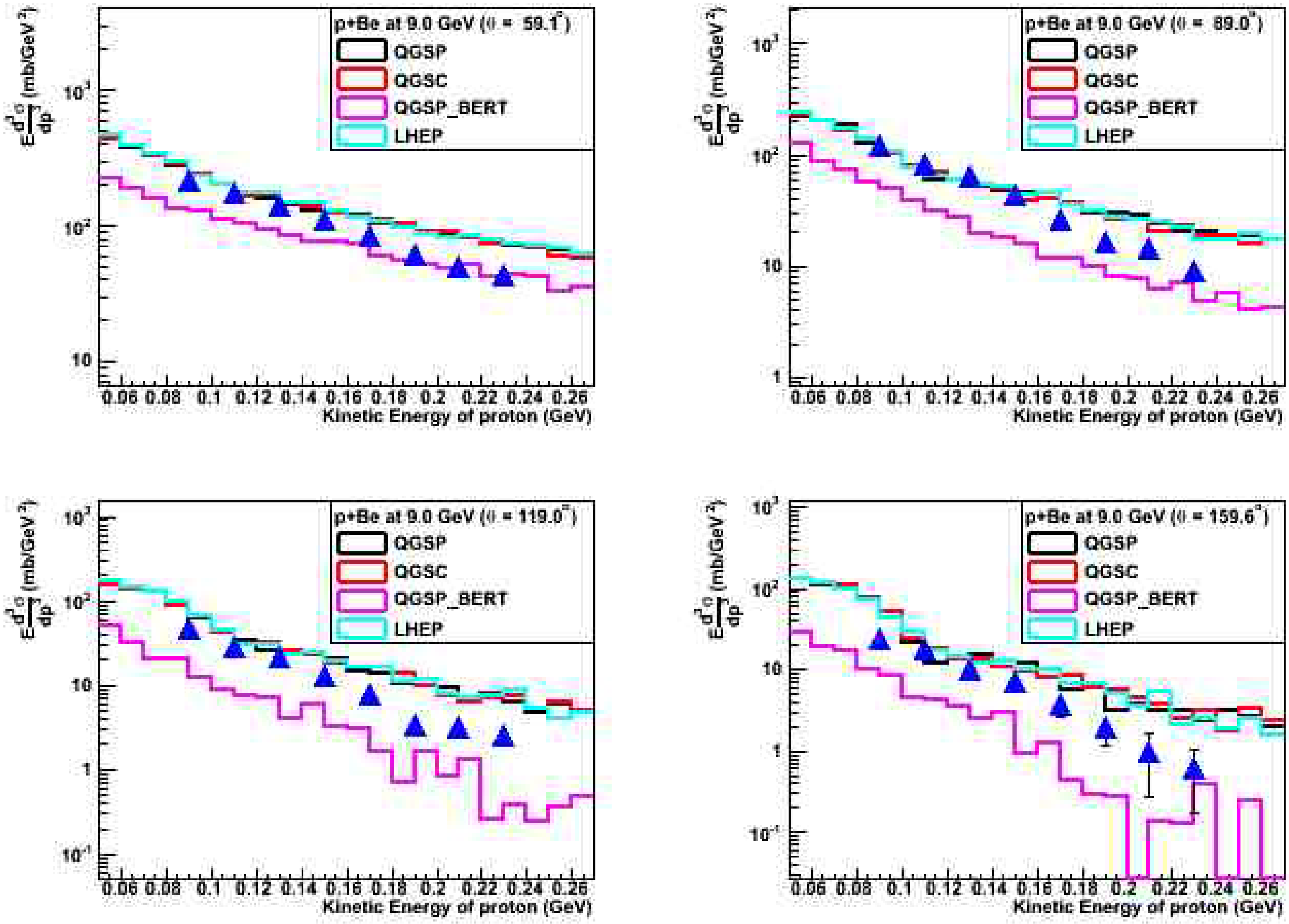
p-Be Collision at 6.2 GeV/c



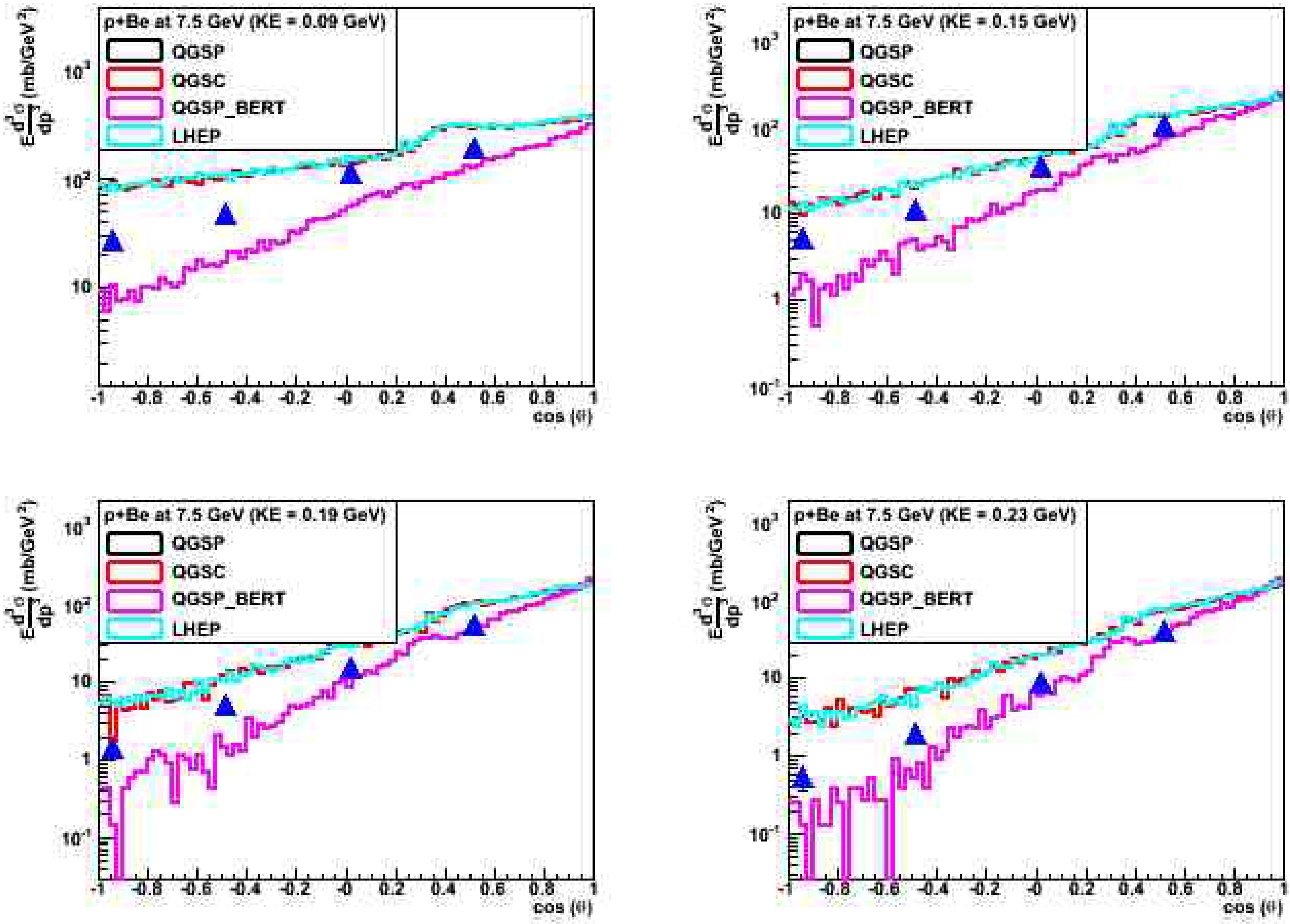
p-Be Collisions at 7.5 GeV/c



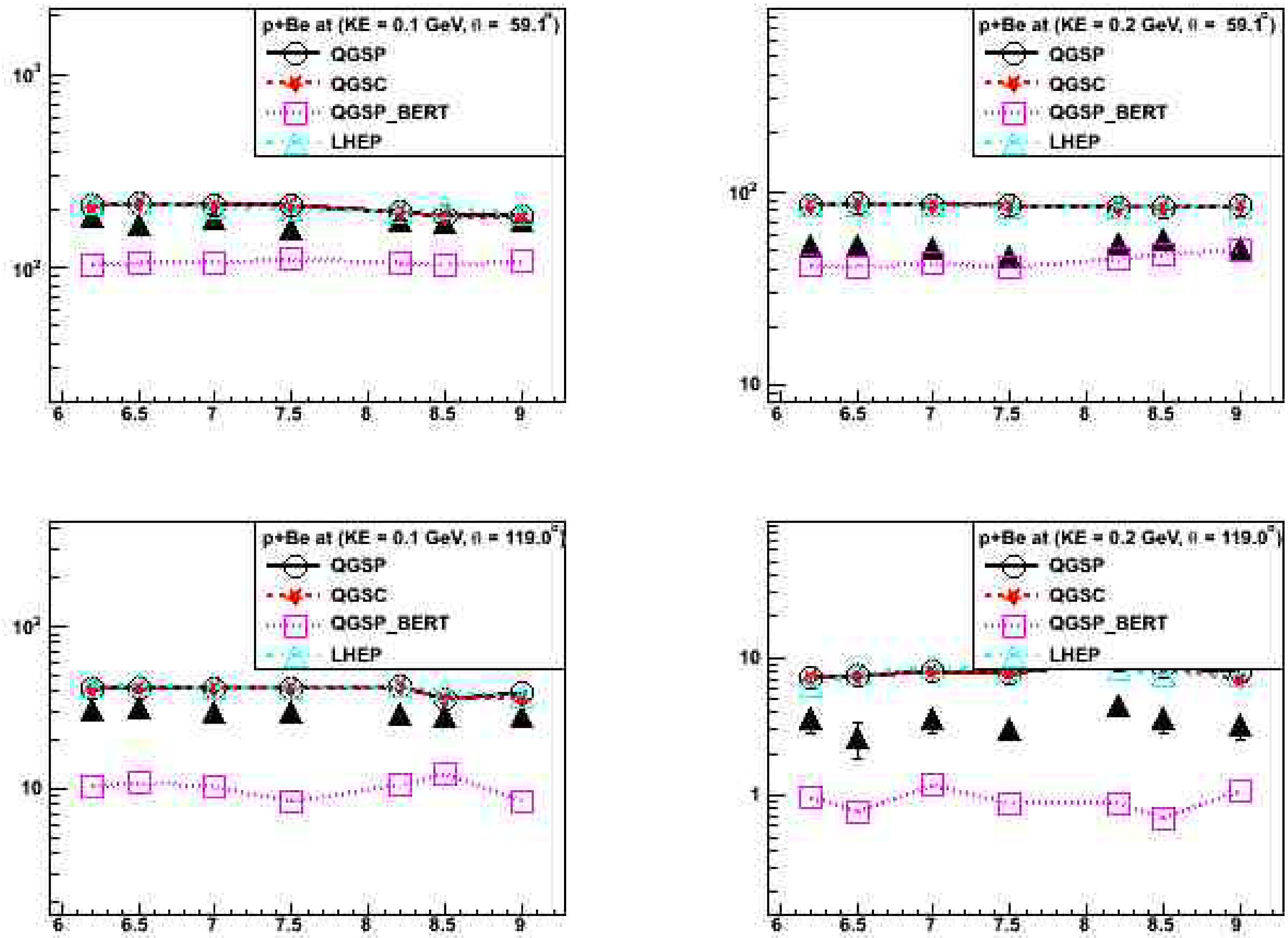
p-Be Collisions at 9.0 GeV/c



Angular Dependence



Energy Dependence



General Observation

- QGSP, QGSC, FTFP and LHEP models predict very similar inclusive proton cross sections and differential distributions for p-Be collision at 6-9 GeV/c
- QGSP_Bertini model gives very different predictions than the other 4 models
- Difference is seen in absolute cross section as well as in angular distribution (larger separation for back scattered protons)
- Experimental data (ITEP)lie some where in between
- Protons with low kinetic energy agree better with QGSP-like models while those with higher energies agree better with Bertini model

Documentation

- ❑ Improvements and Extension of the documentation of physics validation and verification of Geant4 hadronics.
  - Brief overview of the physics models
  - Distinguish comparisons with thin target data, full setup
  - Document the input cross sections used
  - Clean up and complete the references of the sources used
- ❑ Setting up a repository of validation results
- ❑ Use Geant4 website at Fermilab to put in the new material:

http://geant4.fnal.gov/hadronic_validation/validation_plot.htm

- ❑ The zeroth version exists. It is rapidly getting updated

Header Page

Geant4 Physics Validation - Mozilla Firefox

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http://geant4.fnal.gov/hadronic_validation/validation_plots.htm

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Introduction

The aim of this document is to give a brief overview of the available physics models in Geant4 and to present, via comparison vs various experimental data, the range of validity for each of them.
In addition to the information on the physics models available within Geant4, here we collect references to the experimental data available to us for the benchmarking, as well as plots that show how well Geant4 can simulate a variety of physics processes.
Results and plots are provided as they become available and are updated from time to time. Brief description of each simulation test is also given.

Brief Overview of the Geant4 Physics Models

Geant4 offers modeling options, data- or theory-driven, for electromagnetic and hadronic physics process, with different accuracy, computing requirements, strengths and weaknesses in describing particular physics aspects.
For details of the physics models available in Geant4, please follow the links in the column on righthand side.
Of the theory-driven models, this document currently contains results on the following:

- Chiral Invariant Phase space (CHIPS) model for stopped particles and low energy gammas (up to 151MeV)
- Precompound model for low energy protons (25-100MeV)
- High Precision Neutron model for low energy neutrons (20MeV)
- Bertini and Binary cascade models for particles at energies below 10GeV
- Quark Gluon String (QGS) model for particles at energy above 20GeV

Of the data-driven models, the following models results are currently available for:

- Low Energy Parametrized (LEP) model for 730MeV protons
- High Energy Parametrized (HEP) models for high energy protons (67GeV, 400GeV)

Related Links

Electromagnetic Physics

- Standard EM model
- Low Energy EM model

Hadronic Physics

- QGS model
- FTF model
- Bertini cascade
- Binary cascade
- Precompound model
- CHIPS model
- LEP model
- HEP model

Validation Data Catalog

- Stopped anti-proton
- Stopped pion
- Gamma incident
- Proton incident
- Pion incident
- Kaon incident

Tests and Results

Results and plots comparing Geant4 physics predictions with experimental measurements are classified here into three categories:
thin target, **full setup** and **input cross section**.
Thin target comparisons (also referred to as verifications) are meant to test individual Geant4 models or processes in isolation from all other physical proceses. In the laboratory this is usually accomplished by scattering from thin targets, which allows a clean and detailed study of single hadronic interactions.
Full setup comparisons are validations of integrated Geant4 simulations against results from complex experiments or test beams in which all physical processes are included.
Cross section data is used to calculate the mean free path to interaction and to normalize model predictions. In most cases, these cross sections are calculated directly or parameterized from data. Here the calculated or parameterized cross sections are compared to the original data sets.

Thin Target Comparisons

- Electromagnetic
- Hadronic
  - Stopped particles
  - Low Energy: thermal to 100 MeV
  - Medium Energy: 100 MeV to 20 GeV
  - High Energy: 20 GeV to 1 TeV

Full Setup Comparisons

- High Energy Physics Experiments
- Thick Targets
- Geant4 Examples
- User-contributed

Input Cross Sections

- Electromagnetic
- Hadronic
  - Elastic cross sections
  - Inelastic cross sections

http://geant4.web.cern.ch/geant4/index.shtml

Thin Target

Medium Energy Hadronic Verifications - Mozilla Firefox

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http://geant4.fnal.gov/hadronic_validation/validation_plots/thin_target/hadronic/medium_energy/index1.shtml

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Medium Energy Verifications

These tests compare Geant4 predictions with experimental data from about 100 MeV up to 20 GeV.

- 113-800 MeV protons (various targets)
- 123, 151 MeV gammas
- 380 MeV protons (isotope production)
- 400 MeV heavy ions
- 730 MeV protons
- 1.5 GeV protons on Pb
- 3.0 GeV protons on Pb
- 6.2GeV, 7.5GeV, and 9.0GeV proton on Be

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Last updated: 16 Feb 2007

http://geant4.fnal.gov/hadronic_validation/validation_plots/thin_target/hadronic/medium_energy/test_itep/itep_data.shtml

ITEP (I)

Proton of 6.2 - 9.0 GeV on Be and other targets - Mozilla Firefox

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http://geant4.fnal.gov/hadronic_validation/validation_plots/thin_target/hadronic/medium_energy/test_itep/itep_data.shtml

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Experiment Description

Proton beams of energy between 6.2 GeV to 9.0GeV are incident on several targets. Inclusive proton production at various angles and in several kinetic energy bins are measured. Currently, only data for Be target are used for comparison.

- **Data references**: Yu.D. Bayukov et al., Preprint ITEP-148-1983;
  Yu.D. Bayukov et al., Angular Dependences Of Inclusive Nucleon Production In Nuclear Reactions At High-Energies And Separation Of Contributions From Quasifree And Deep Inelastic Nuclear Processes, Sov.J.Nucl.Phys.42:116-121,1985;
  HEPDATA

Simulation Conditions

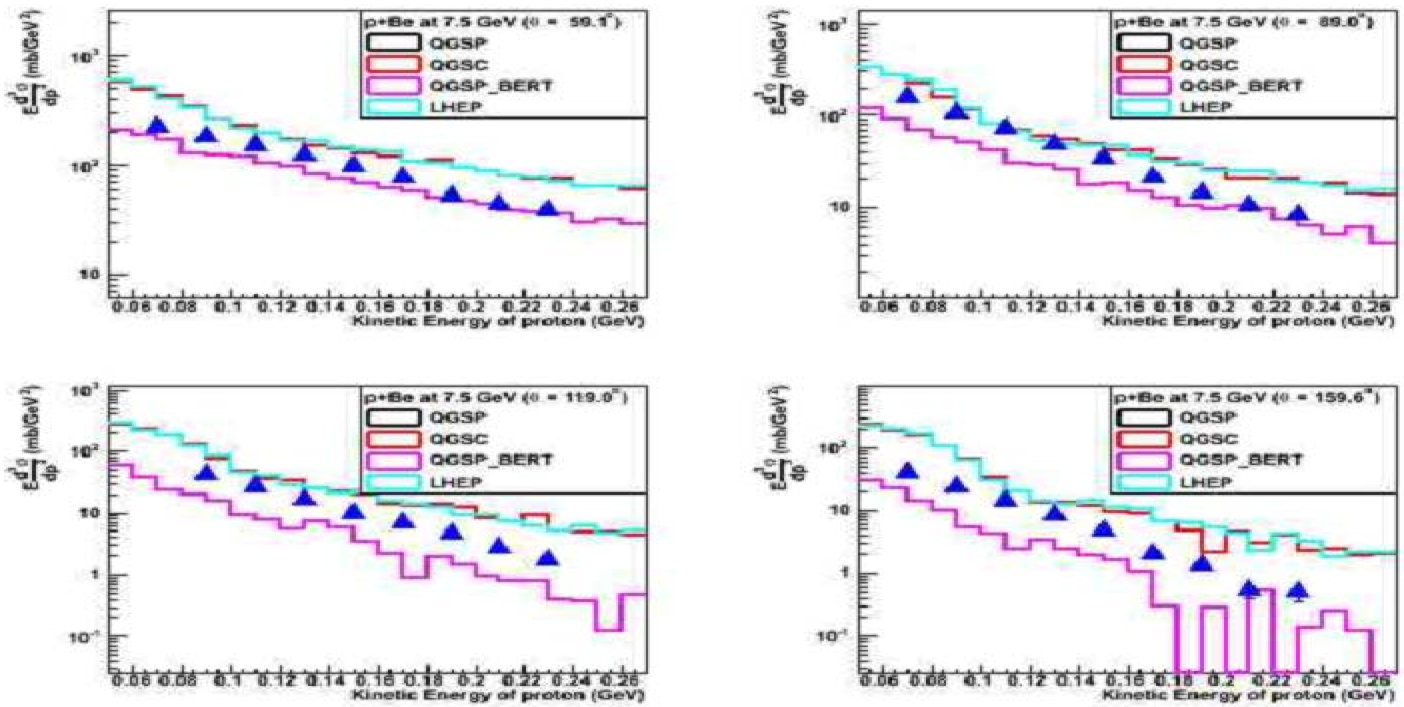
- Geant4 version: 8.3.p01
- Models / Physics Lists: LHEP, QGSP, QGSC, QGSP-Bertini

Results

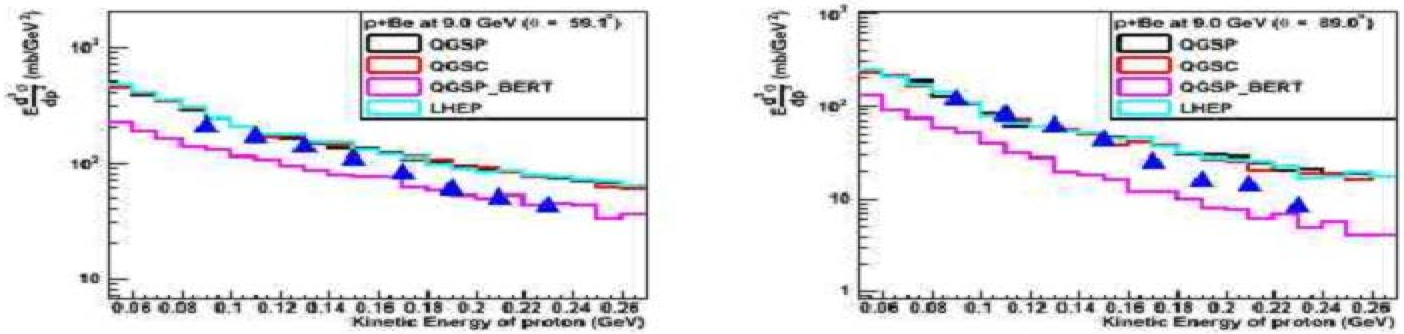
- Measured and simulated inclusive proton production in proton-Be interaction, as a function of kinetic energy, is illustrated Figures 1, 2,and 3, for different energies and at different angles of the beam particle.
  The plots in Fig.1 are for 6.2GeV proton incidentat the Be target at 59.1, 89.0, 119.0, and 159.6 degree, respectively, while the plots in Fig.2 are for 7.5GeV incident proton, and the plots in Fig.3 are for 9.0GeV incident proton.
  The blue triangles in all plots represent experimental data, and the color-coded solid lines stand for different Geant4 physics lists, as indicated in the box in the upper corner of each plot.
- Measured and simulated inclusive proton production in proton-Be interactions, as a function of the incident angle, is illustrated in Figures 4, 5, and 6, for different energies of the beam particle and different energies of the outcoming proton.
  The plots in Fig.4 are for 6.2GeV beam energy and for 0.09GeV, 0.15GeV, 0.19GeV, and 0.23GeV kinetic energy of the outcoming proton, respectively, while the plots in Fig.5 are the same quantities for 7.5GeV beam energy, and the plots in Fig.6 are for 9.0GeV incident proton.
  The blue triangles in all plots represent experimental data, and the color-coded solid lines stand for different Geant4 physics lists, as indicated in the box in the upper corner of each plot.
- **We consistently observe** that, for all beam energies, at all angles of incidence, and for all kinetic energies of the secondary proton, the theory-driven QGSP_BERT physics list models inclusive proton cross-section below that measured in the experiment, while predictions of the physics lists that employ parametrized low-energy hadronic model (QGSP, QGSC, LHEP) are above the data.

Done

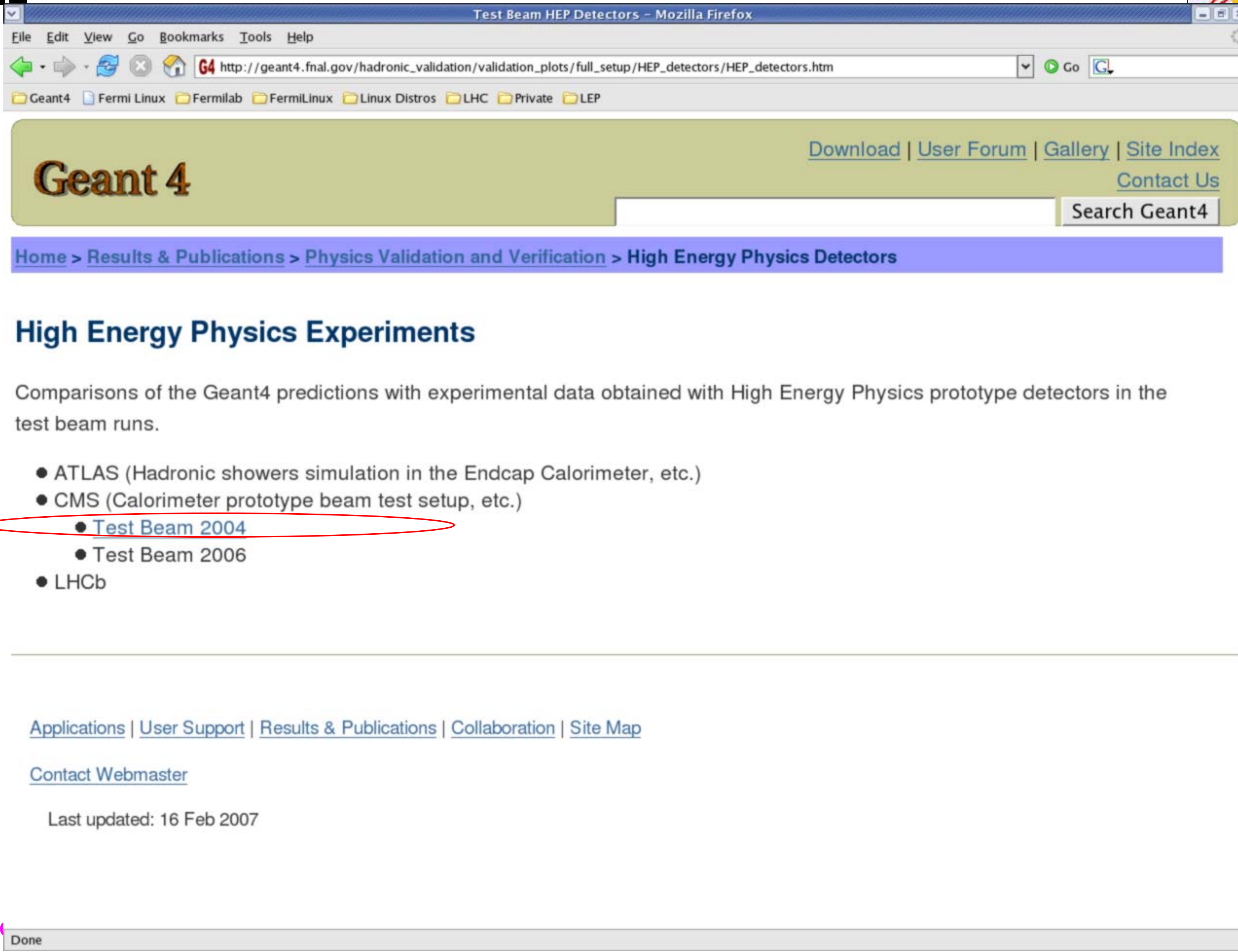
ITEP (II)



- **Figure 3: 9.0GeV proton incident on Be target at 59.1, 89.0, 119.0, or 159.6 degree - inclusive proton yield as a function of kinetic energy, for different incident angles**



Complete Setup



CMS (I)

CMS HCAL TB Setup - Mozilla Firefox

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http://geant4.fnal.gov/hadronic_validation/validation_plots/full_setup/HEP_detectors/CMS/cms_calo_2004.shtml

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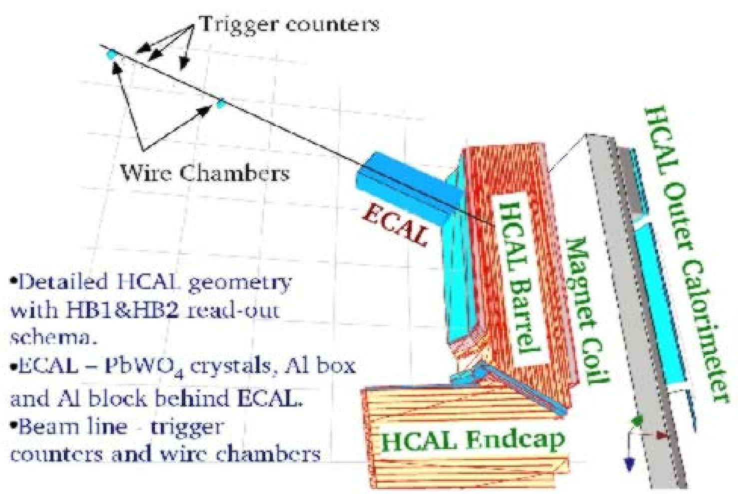
Experiment Description

CMS ECAL+HCAL Test Beam Setup - Run 2004.

- **Data references**: S.Piperov, in Proceedings of the HSS2006 Workshop, Sept.6-8, 2006, Batavia IL USA, 195-204 (2006) also private communications with CMS HCAL group

The elements included in the CMS Calorimetric setup that were present in the 2004 test beam run are shown below:

Test Beam 2004 Calorimetry Setup



Only the response from Electromagnetic Calorimeter module (ECAL) and Barrel Hadronic Calorimeter wedges (HB) were considered in this data analysis and simulation, that is:

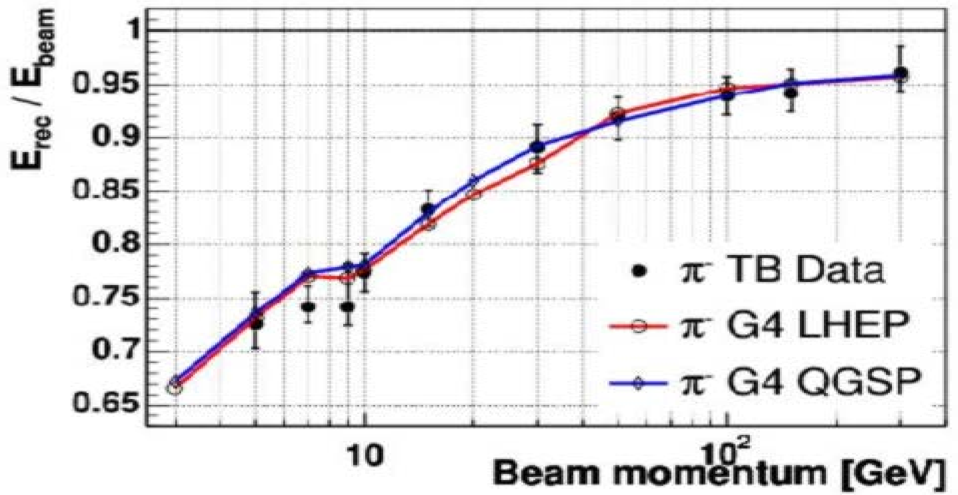
- 7x7 matrix of the prototype ECAL Lead Tungstate (PbWO4) crystals, read out by individual photo-multipliers; each crystal has a face front of 22x22mm**2 and is 23cm long (~26 radiation lengths)
- Two wedges of the Barrel HCAL (HB); the CMS HB is a sampling calorimeter with 5mm thick copper absorber plates interleaved with 3.7mm thick scintillator sheets; scintillator tiles are optically grouped together in towers covering equal surface (0.087x0.087) in eta-phi scape, and are read out together by Hibrid Photo Diodes; two readout schemes were implemented: tower-wise (as usual) and layer-wise which allowed for measurement of the longitudinal shower profiles in the calorimeter

Simulated detector response was studied at the level of energy deposition in active materials. No detailed simulation of the detector noise was performed. Instead, simple gaussian-distributed noise with amplitudes matched to

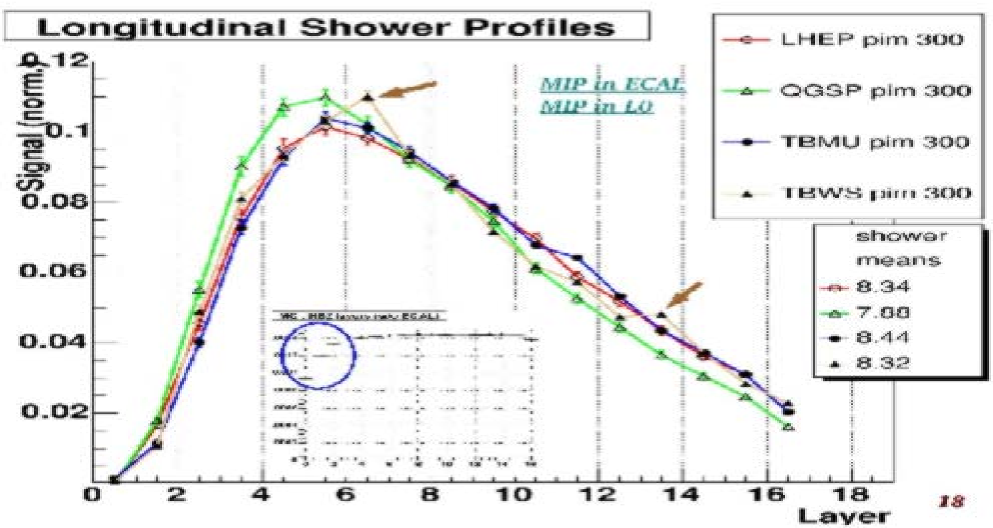
CMS (II)

Plots

- Linearity of pion responce for a combined ECAL+HCAL system



- Longitudinal Profile of the 300GeV pion



Summary and Outlook

- FNAL group has started on two different fronts in the validation and verification of the hadronic package of Geant4
- Updated and extended version of documentation of the validation results now exists (Work in progress)
- Started comparing Geant4 predictions with data in the intermediate energy region where very little verification has been done in the past
- Soon more comparisons will be done for inclusive proton production for a wide range of targets