Comparison of Geant4 simulation data with hadron shower data in the PAMELA experiment

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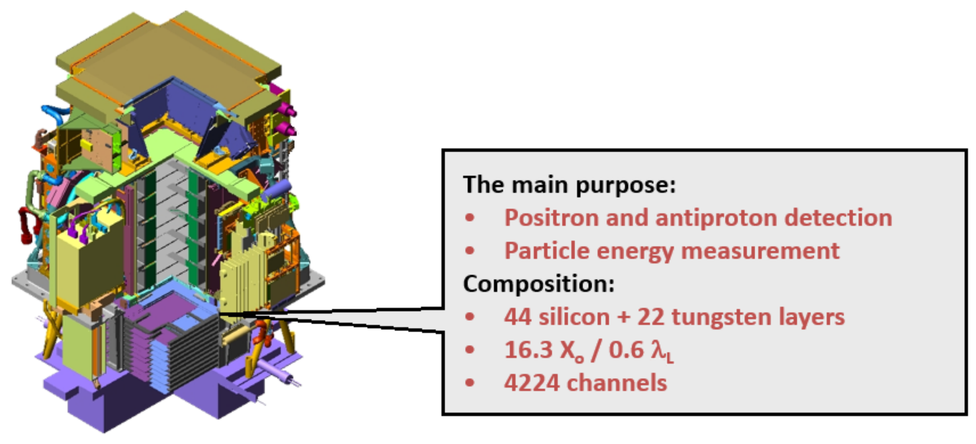
Introduction

PAMELA (**P**ayload for **A**ntimatter **M**atter **E**xploration and **L**ight-nuclei **A**strophysics) — a cosmic ray research module (2006 – 2016). The main goal of the device: positron and antiproton detection in cosmic rays.



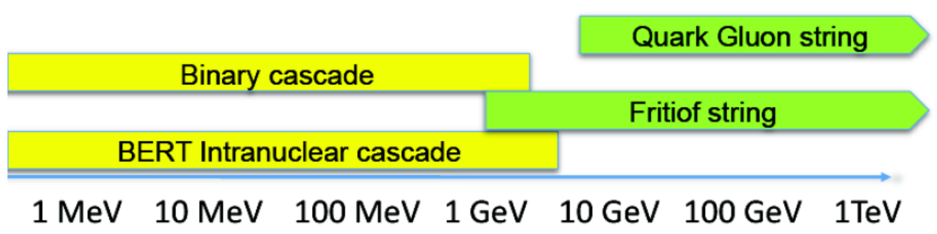
PAMELA calorimeter consists of 22 tungsten plates + 22×2 scintillating silicon layers each with 96 read-out strips in each (X and Y) projections.

The goal of our work is to choose appropriate Geant4 hadronic cascade model for different energy ranges.

Geant4 Physics Lists

Simulation data (protons):

- QGSP_BERT
  Quark-Gluon String model with Bertini cascade.
- FTFP_BERT
  Fritiof model with Bertini cascade.
- QGSP_BIC — QGSP with binary cascade.
- QGSP_INCLXX — QGSP with Liege intranuclear cascade model.



Data preprocessing

Selection criteria

Basic criteria: anti-coincidence system; time-of-flight system; tracking system (correctly restored trajectory).

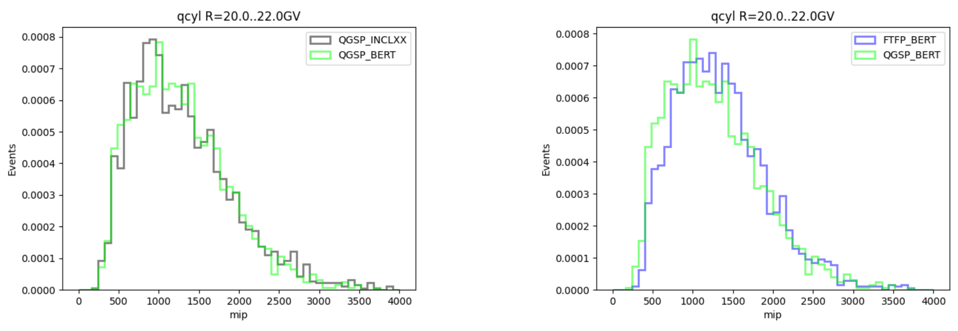
Cascade selection: at least 150 strips triggered in calorimeter; energy loss at least 500 mip.

Hadronic shower descriptors

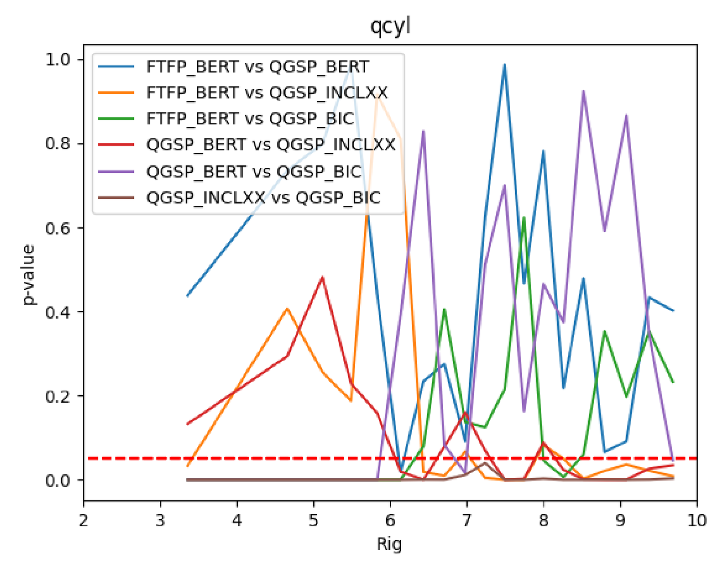
- `qcyl, ncyl` — energy loss and number of triggered strips in a cylinder around shower axis ($R = 8$ strips).
- `qtr, ntr` — energy loss and number of triggered strips in a cylinder around shower axis ($R = 4$ strips).
- `qcore, ncore` — energy loss and number of triggered strips in a cylinder around shower axis up to the shower maximum ($R = 2R_M$, R_M is Moliere radius)
- `planemaxy` — number of plane with maximal energy loss (Y projection).
- `nstrip` — total number of triggered strips.

Comparison of models

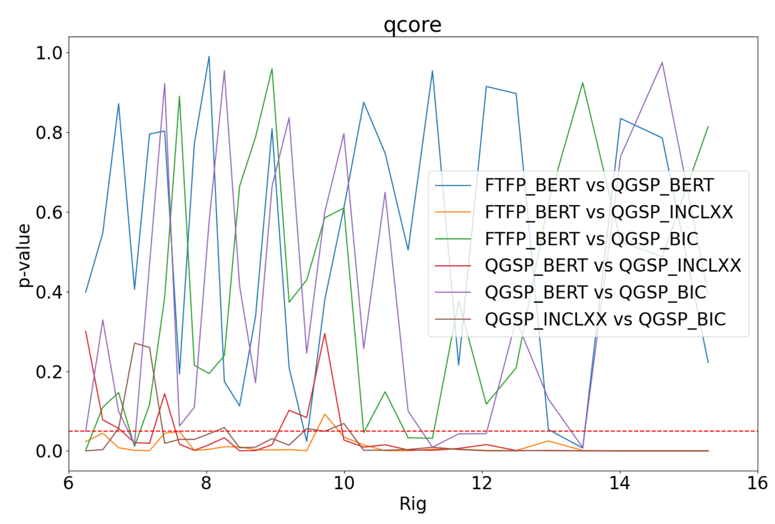
- Consider a narrow rigidity range.
- Calculate shower descriptors for simulation events in this range.
- Compare distributions for different models by two-sample goodness-of-fit test (KS – test or CvM – test).



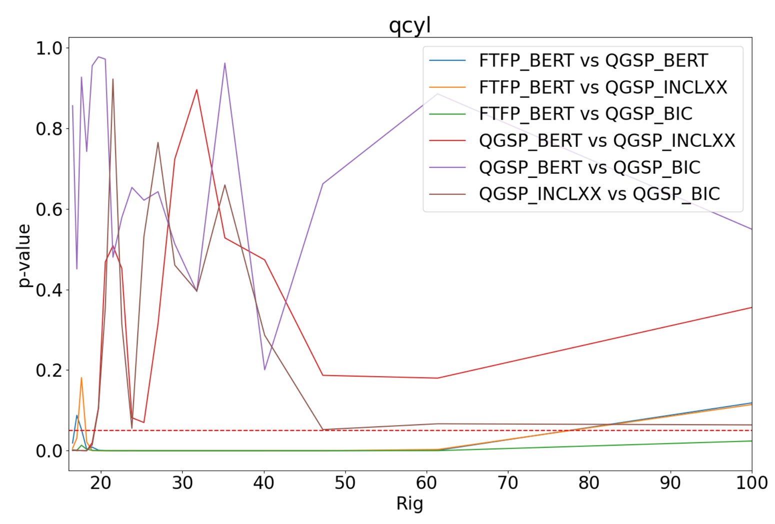
Rigidity < 10 GV: QGSP_BIC differs from other models.
On figure: p-value for KS-test ($\alpha = 0.05$).



Rigidity 6..16 GV: QGSP_INCLXX differs from other models.
On figure: p-value for KS-test ($\alpha = 0.05$).

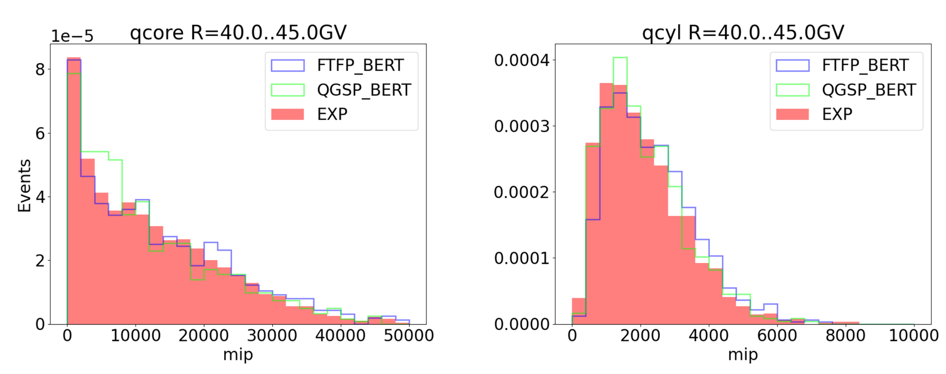


Rigidity > 16 GV: FTFP_BERT differs from other models.
On figure: p-value for KS-test ($\alpha = 0.05$).

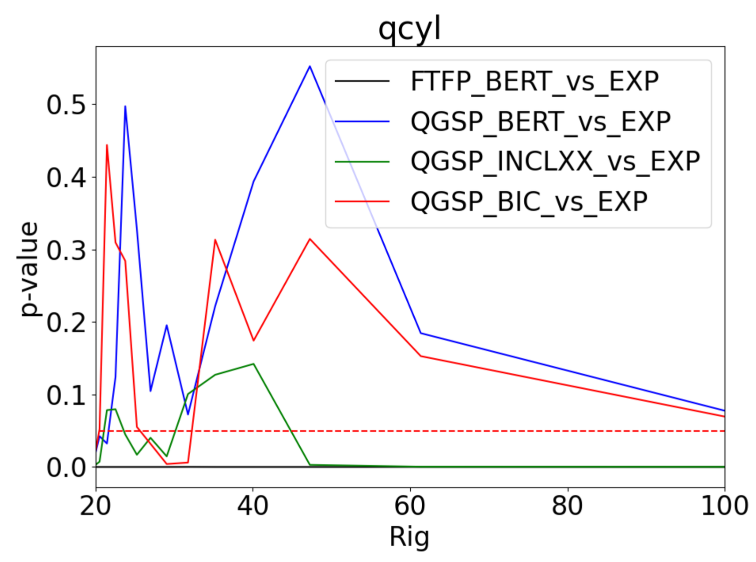


Comparison of simulation and experiment

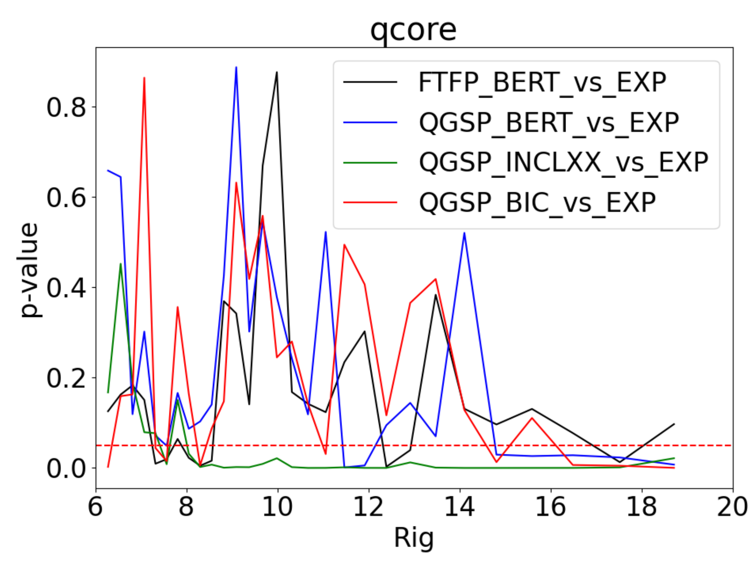
Distributions of `qcore` and `qcyl` parameters for simulation and experiment:



$R > 20$GV: QGSP_BERT model agrees with experiment.



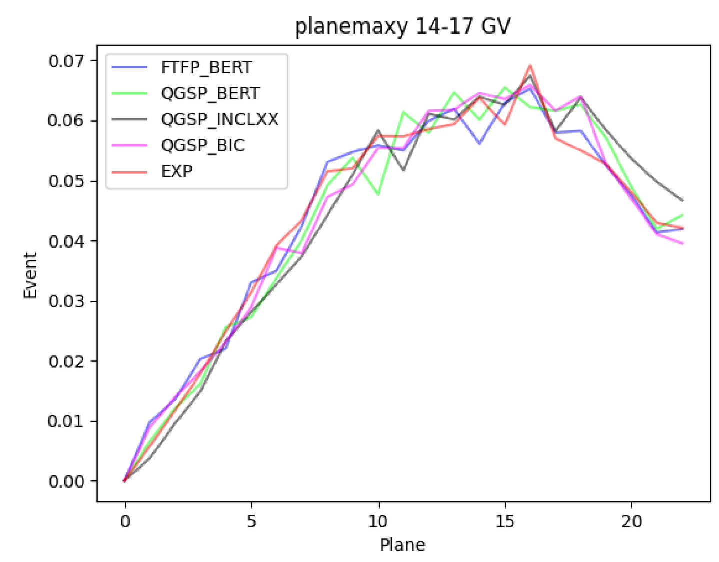
$8 < R < 20$GV: QGSP_INCLXX model disagrees with experiment.



Depth of cascade development:

`planemaxy` – number of plane with maximal energy loss (Y projection).

All models agree with experiment.



Results

- Low rigidities (< 6GV): the binary cascade simulation gives distributions of parameters, which are not agree with Bertini and Liege cascades.
- For R = 6..15 GV: physics lists QGSP and FTFP do not agree with QGSP_INCLXX model, then (supposing agreement between BERT and INCLXX) we conclude that INCLXX and QGSP / FTFP are different in cascade simulation.
- At the large (> 20 GV) rigidities we observe the difference between QGS and FTF models.

From comparison with experiment we conclude:

- For the high energies statistical agreement is reached for QGSP_BERT model.
- For the medium energies (6..15 GV) there is no statistical difference between FTFP and QGSP models.
- For the low energies agreement is reached for Bertini cascade.
- Liege cascade model agrees with experimental data for rigidities up to 6–7 GV, despite of it is used for rigidities < 20GV.