Comparison of hadron shower data in the PAMELA experiment with Geant 4 simulations

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PamVMC

Software:

Program	Version
Geant 4	4.10.01 patch 2 (august 2015)
CLHEP	2.2.0.4
Root	5.34.23
VGM	4.2
Geant 4 VMC	3.1

Names of physical models of Geant 4

[Hadronic, high energies] _ [Hadronic, low energies] _ [Neutrons, increased precision] _ [Electromagnetic]

- FTF — or lists based on a modeling using the FTF model for high energy hadronic interactions of protons, neutrons, pions, and Kaons; FTF is FRITIOF like string model
- QGS — quark-gluon string model
  - P — Precompound model used for nuclear de-excitation
  - C — CHiral Invariant Phase Space (CHIPS)

Names of physical models of Geant 4

- BERT — Bertini intranuclear cascade model
- BIC — Binary Intranuclear Cascade model
- INCLXX — Liege Intranuclear Cascade model
- HP — High Precision

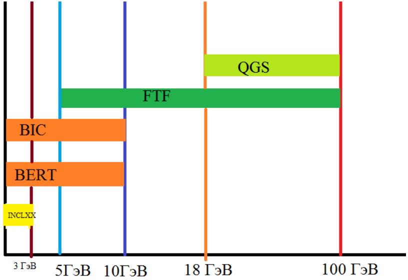
Without option — standard electromagnetic package. Electromagnetic computations of higher precision:

- EMY — created for ATLAS
- EMZ — created for CMS
- LIV — Livermore
- PEN — PENELOPE (PENetration and Energy LOss of Positrons and Electrons)

Used models

Energies: $1, 1.5, 2, 3, 4, 5 GeV$.

FTFP_BERT_HP	FTF_BIC	FTFP_INCLXX_HP
FTFP_BERT_HP_EMY	FTF_BIC_EMY	FTFP_INCLXX_HP_EMY
FTFP_BERT_HP_EMZ	FTF_BIC_EMZ	FTFP_INCLXX_HP_EMZ
FTFP_BERT_HP_LIV	FTF_BIC_LIV	FTFP_INCLXX_HP_LIV
FTFP_BERT_HP_PEN	FTF_BIC_PEN	FTFP_INCLXX_HP_PEN



Used models

Energies: $7.5, 10, 12.5, 15 GeV$.

FTFP_BERT_HP	FTFP_INCLXX_HP
FTFP_BERT_HP_EMY	FTFP_INCLXX_HP_EMY
FTFP_BERT_HP_EMZ	FTFP_INCLXX_HP_EMZ
FTFP_BERT_HP_LIV	FTFP_INCLXX_HP_LIV
FTFP_BERT_HP_PEN	FTFP_INCLXX_HP_PEN
QGSP_BERT_HP	QGSP_INCLXX_HP
QGSP_BERT_HP_EMY	QGSP_INCLXX_HP_EMY
QGSP_BERT_HP_EMZ	QGSP_INCLXX_HP_EMZ
QGSP_BERT_HP_LIV	QGSP_INCLXX_HP_LIV
QGSP_BERT_HP_PEN	QGSP_INCLXX_HP_PEN

Used models

Energies: $25, 35, 50 GeV$.

FTFP_BERT_HP_PEN
QBBC_PEN
QGSP_BERT_HP_PEN
QGSP_FTFP_BERT_PEN
FTFP_INCLXX_HP_PEN
QGSP_INCLXX_HP_PEN

Selection criteria

Simulation and experiment:

- $CARD = 0$ & $CAT = 0$
- $S11 \leq 1$ & $S12 \leq 1$ & $S11 + S12 < 0$ & $S21 \leq 1$& $S22 \leq 1$ & $S21 + S22 > 0$ & $S31 + S32 > 0$
- Found only 1 standard track: $Nx \geq 5$ & $Ny \geq 4$ & $Nstep < 100$ & $isinsideAcceptance$
- Number of singlets: $Nclsx \leq 2$ & $Nclsy \leq 1$
- Trajectory from tracking system goes through calorimeter strip with nonzero energy release.
- Quality of track checking is $\chi^2(\frac{dE}{dx})$. $\frac{dE}{dx}$ is mean energy loss in tracking system.
- Tracks checking using refitted trajectories.
- Selection of particles by multiple measurements of $\frac{dE}{dx}$ in tracking system.
- Limitation of energy release in detectors S1 and S2 of ToF system.

Selection criteria

Experiment:

- $|Rig| > 1.1R_c$ & *lifetime* < 4000, where R_c is geomagnetic cutoff rigidity
- $\beta > 0.1,\ \beta \neq 100$
- $\frac{dE}{dx}(t)$ — ionization energy losses in tracking and time-of-flight systems depending on time t.

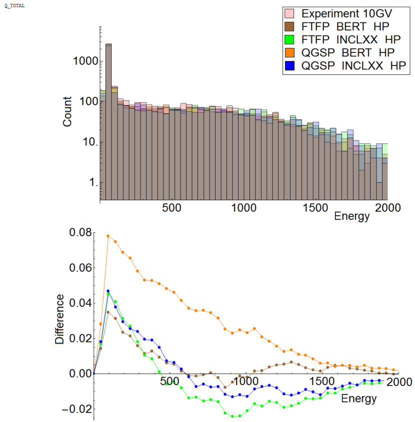
Analyzed characteristics

The response of the PAMELA calorimeter to hadronic showers investigated including shower radius, longitudinal and transverse shower profiles etc.
As an example we show results for the following characteristics:

- Q_{total} — the total energy release in calorimeter
- Q_{max} — the maximum energy detected in a strip
- Q_{pre} — the measured energy deposited in a cylinder of radius 8 strips around the shower axis

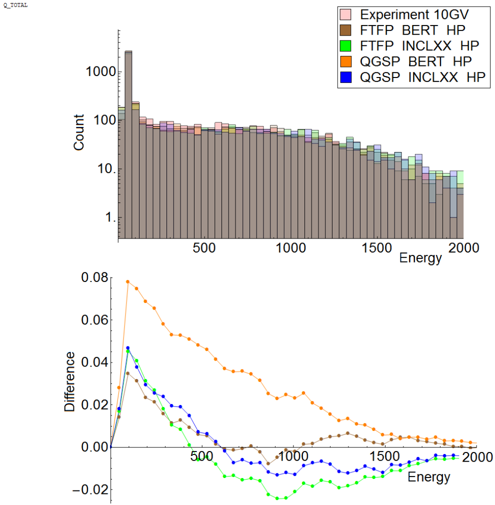
$Q_{total}, R = 10$

The size of sampling is $N = 7500$ particles and threshold for Kolmogorov-Smirnov test is $l = 0.0222$.



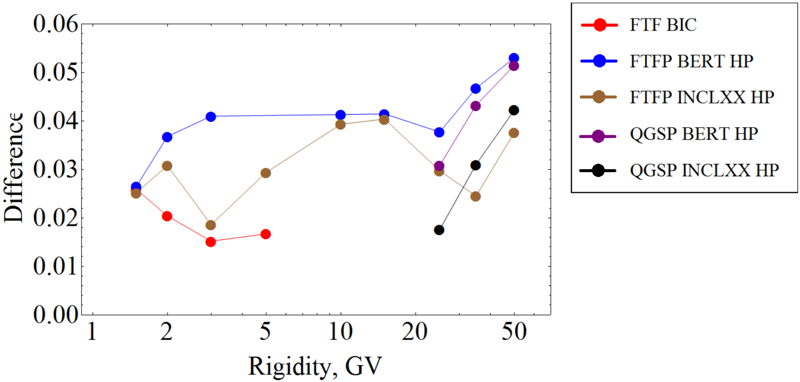
$Q_{total}, R = 50$

$N = 1300, I = 0.0533.$



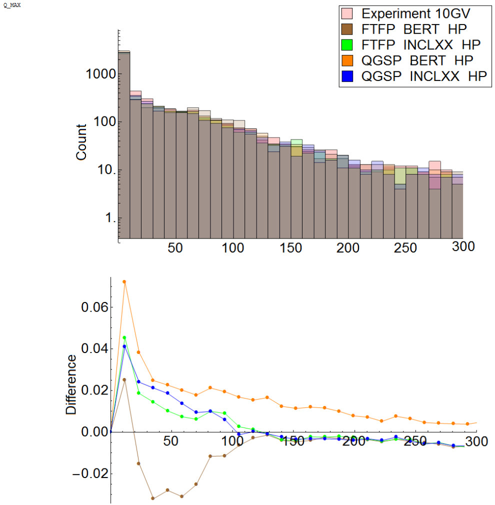
Q_{total}

The following graphs show the value of $max(|CDF[R] - CDF_{exp}[R]|)$ for each R.



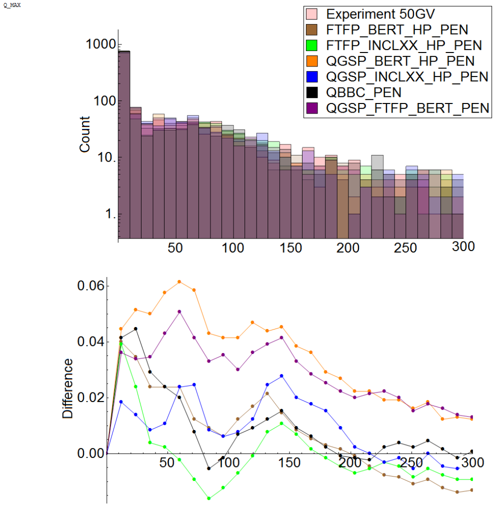
$Q_{max}, R = 10$

$N = 7500, I = 0.0222.$

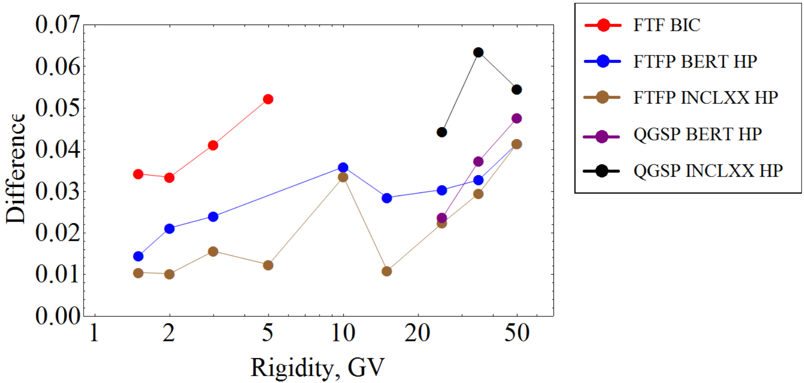


$Q_{max}, R = 50$

$N = 1300, I = 0.0533.$



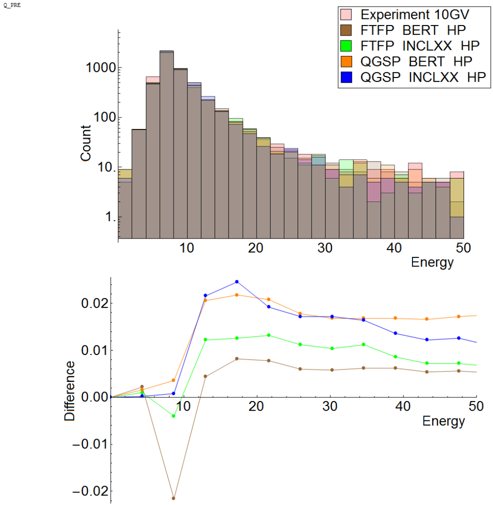
Q_{max}



0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Difference
1
2
5
10
20
50
Rigidity, GV
FTF BIC
FTFP BERT HP
FTFP INCLXX HP
QGSP BERT HP
QGSP INCLXX HP

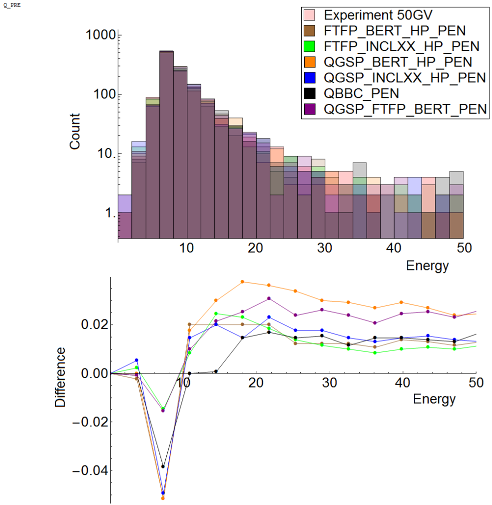
$Q_{pre}, R = 10$

$N = 7500, I = 0.0222.$

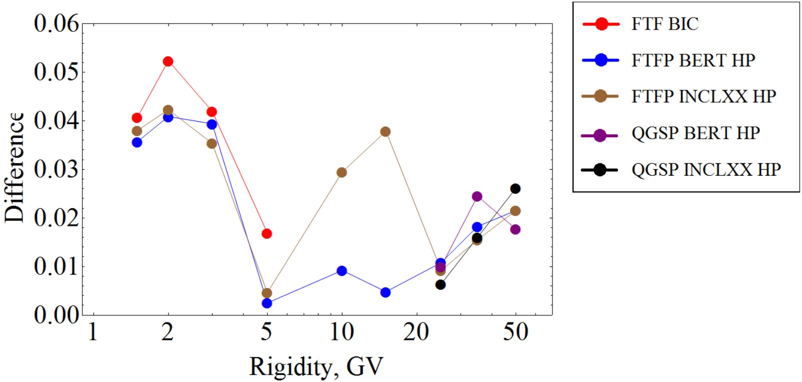


Q_{pre}, $R = 50$

$N = 1300, I = 0.0533.$



Q_{pre}



0.06
0.05
0.04
0.03
0.02
0.01
0.00
Difference
1
2
5
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20
50
Rigidity, GV
FTF BIC
FTFP BERT HP
FTFP INCLXX HP
QGSP BERT HP
QGSP INCLXX HP

Spectrum correction

The corrected on energy resolution of tracking system distribution is the following:

$$\widetilde{g}(Q_{total}, R_0) = g(Q_{total}, R_0) \cdot \widetilde{\delta}(Q_{total}, R_0)$$

Ratio (admixture) of other energies in distribution of Q_{total}:

$$\widetilde{\delta}(Q_{total}, R_0) = \int_{-\infty}^{\infty} g(Q_{total}, R_x)\delta(R_x, R_0)dR_x - \int_{R_0-dR}^{R_0+dR} g(Q_{total}, R_x)\delta(R_x, R_0)dR_x,$$

where

$$\delta(R_x, R_0) = \int_{R_0-dR}^{R_0+dR} \rho(R_x, R)dR$$

Conclusion

- Using Geant 4.10.0.1 and Geant 4 VMC 3.2 lets us achieve better fit in description of hadron interaction than for Geant 4.9.* and Geant 4 VMC 2.*, for which difference was more than 10-15%.
- We were unable to choose one model which can give good results for both high and low energies
- Depending on energy and characteristic of interaction it is recommended to choose separate model for each feature.
- Perform the same analysis for energies higher than 50 GeV