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

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on behalf of the PAMELA collaboration

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Software

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

Isotropic proton flow was simulated.

Naming 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)

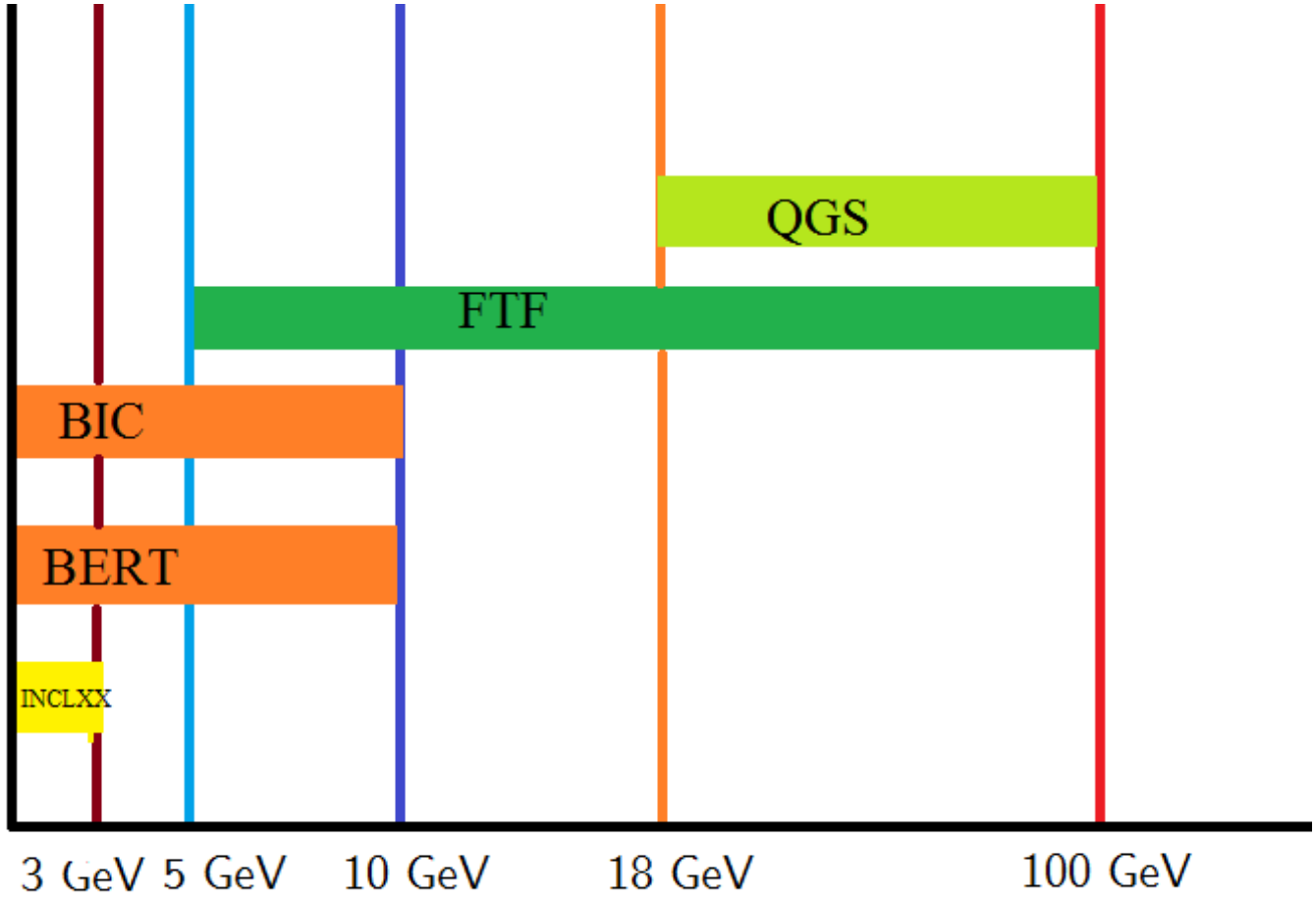
Naming of physical models of Geant 4

- 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



Used models (low energies)

Energies: $1, 1.5, 2, 3, 4, 5, 7.5, 10, 12.5, 15\,GeV$.

FTFP_BERT_HP_* (with EM options)
FTF_BIC_* (with EM options)
FTFP_INCLXX_HP_* (with EM options)
QGSP_BERT_HP_* (with EM options)
QGSP_BERT_HP_* (with EM options)
QGSP_INCLXX_HP_* (with EM options)

Used models (high energies)

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

Proton event was selected if

- it passed through device aperture from the zenith direction;
- it has precisely measured rigidity and speed;
- particle type (proton) is surely detected.

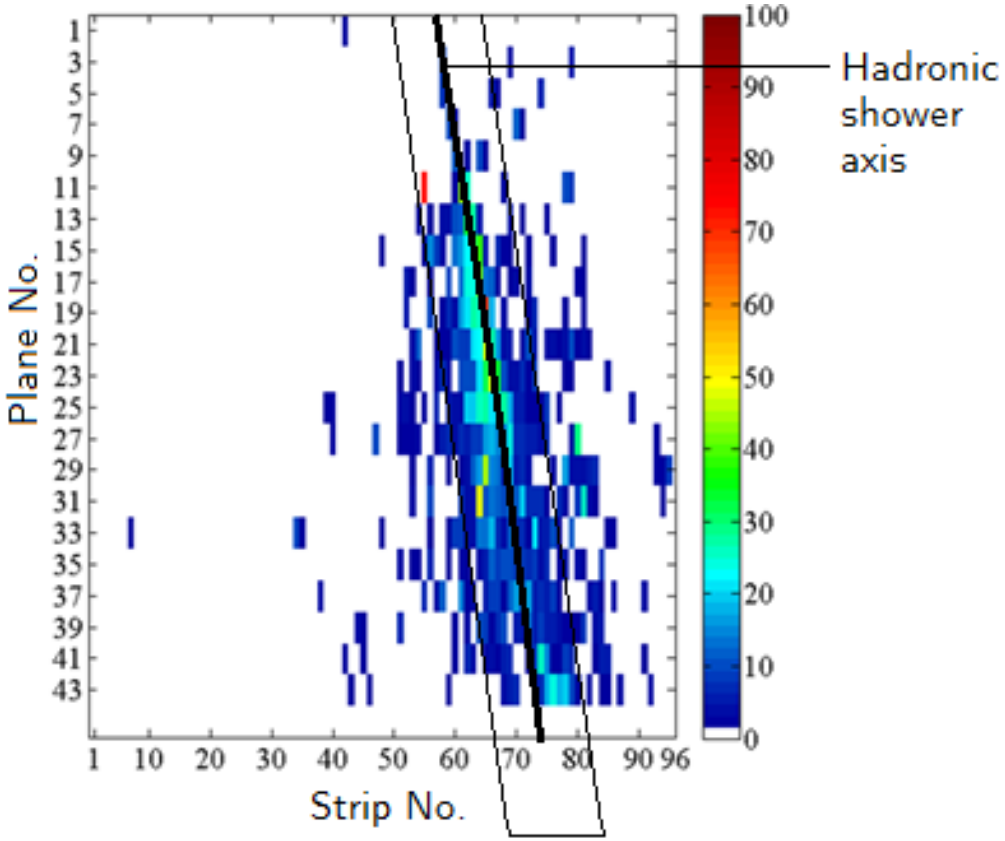
Analyzed characteristics

Analyzed characteristics:

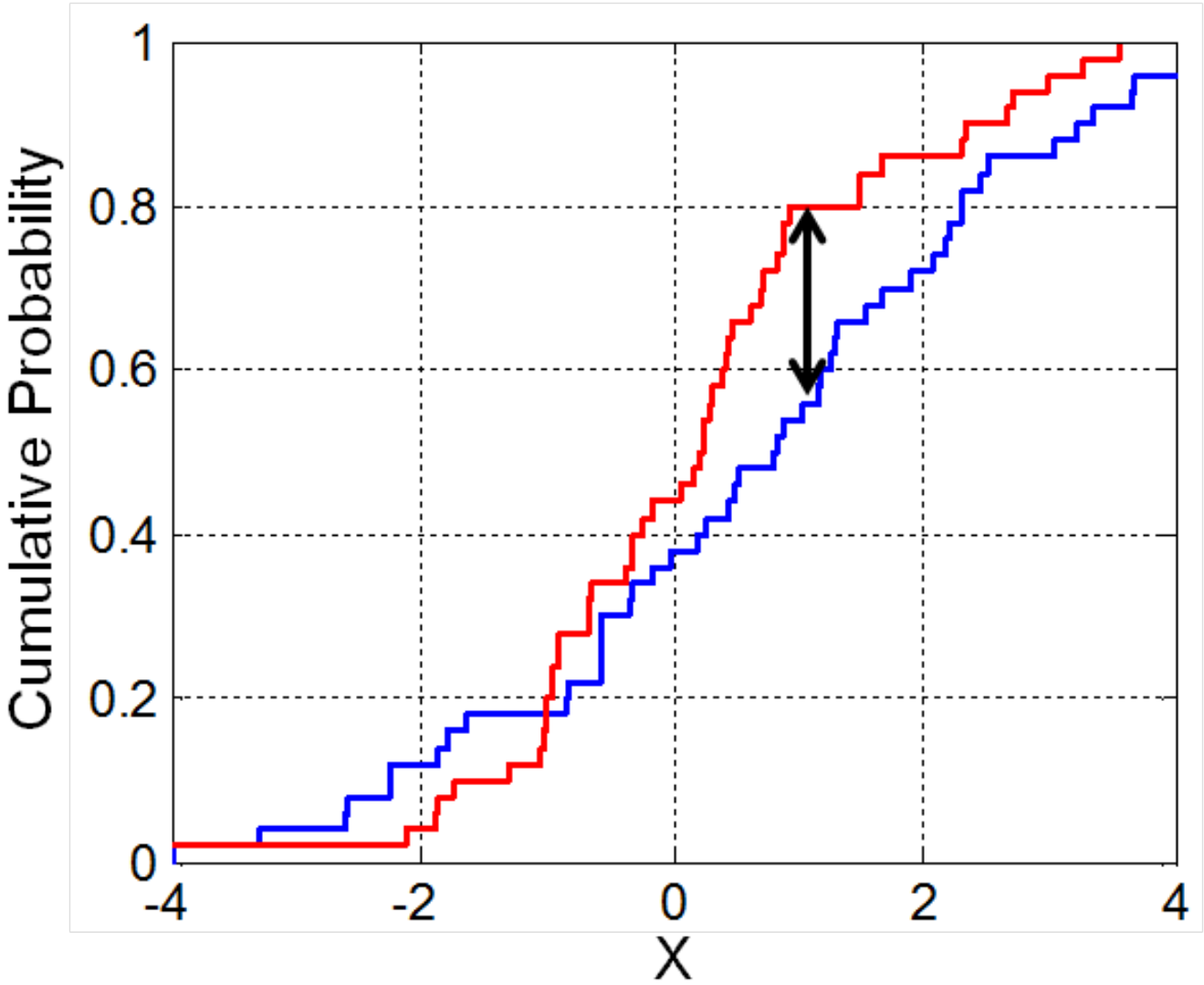
- Q_{tot} — total energy release in the calorimeter,
- Q_{max} — maximum energy release in the calorimeter,
- Q_{track} — energy release along the shower axis,
- Q_{tr} — energy release in the cylinder with radius of 4 strips around the shower axis,
- Q_{cyl} — energy release in the cylinder with radius of 8 strips around the shower axis,
- N_{cyl} — the number of triggered strips in the cylinder with radius of 8 strips around the axis of the shower,
- Q_{pre} — the energy release in the cylinder with radius of 8 strips around the axis of the shower in the first three planes

  etc.

Analyzed characteristics

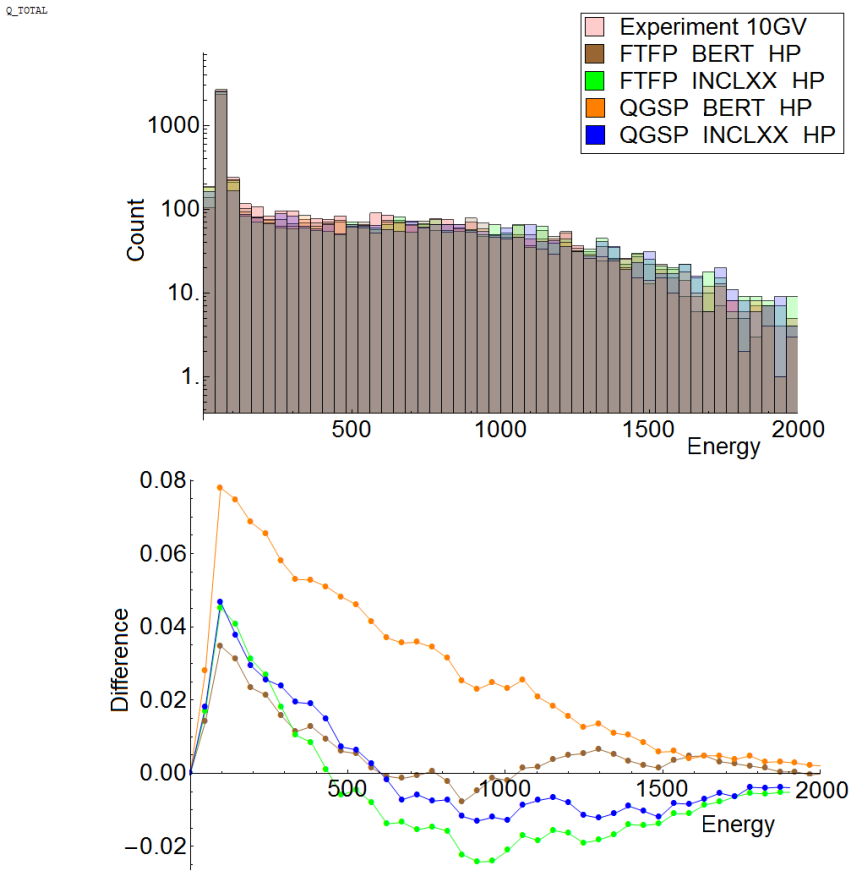


Two-sample Kolmogorov-Smirnov test



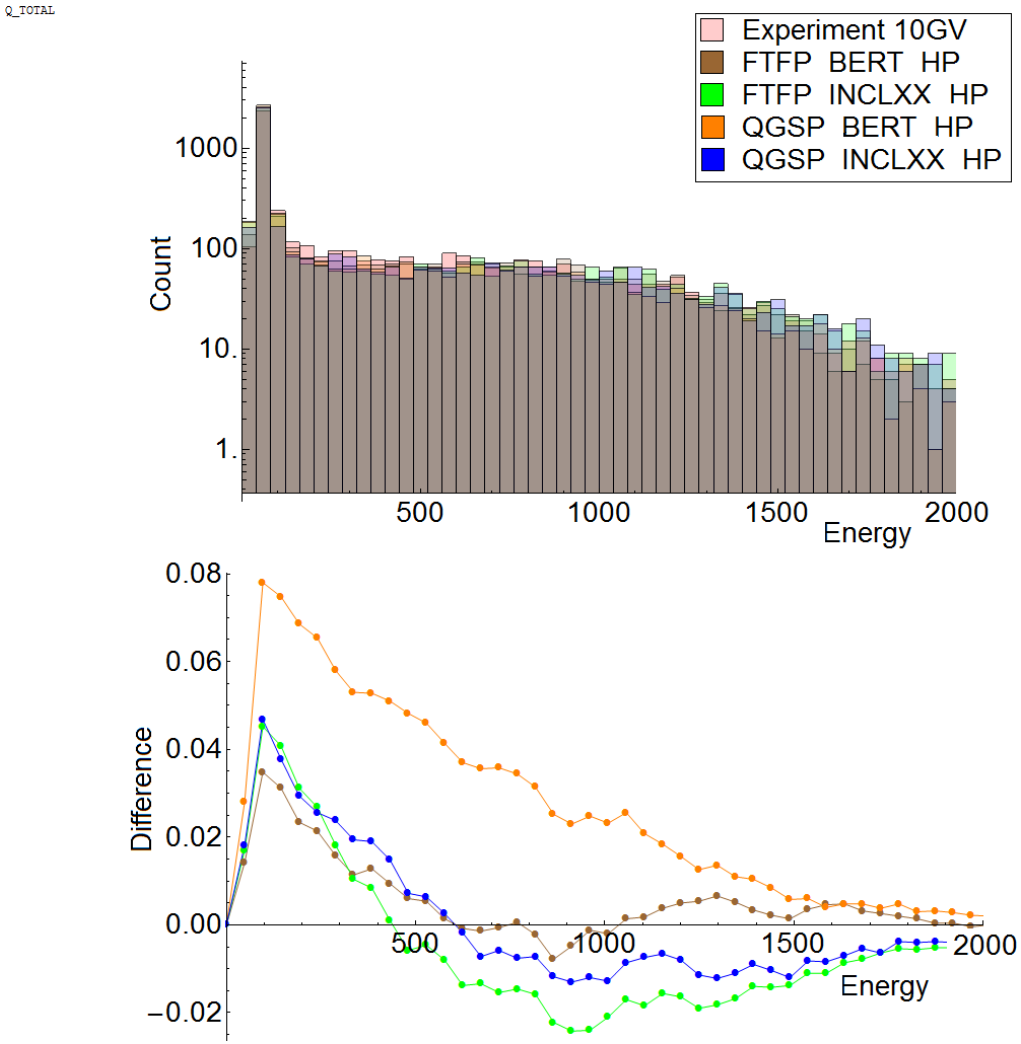
Q_{total}, $R = 10$

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



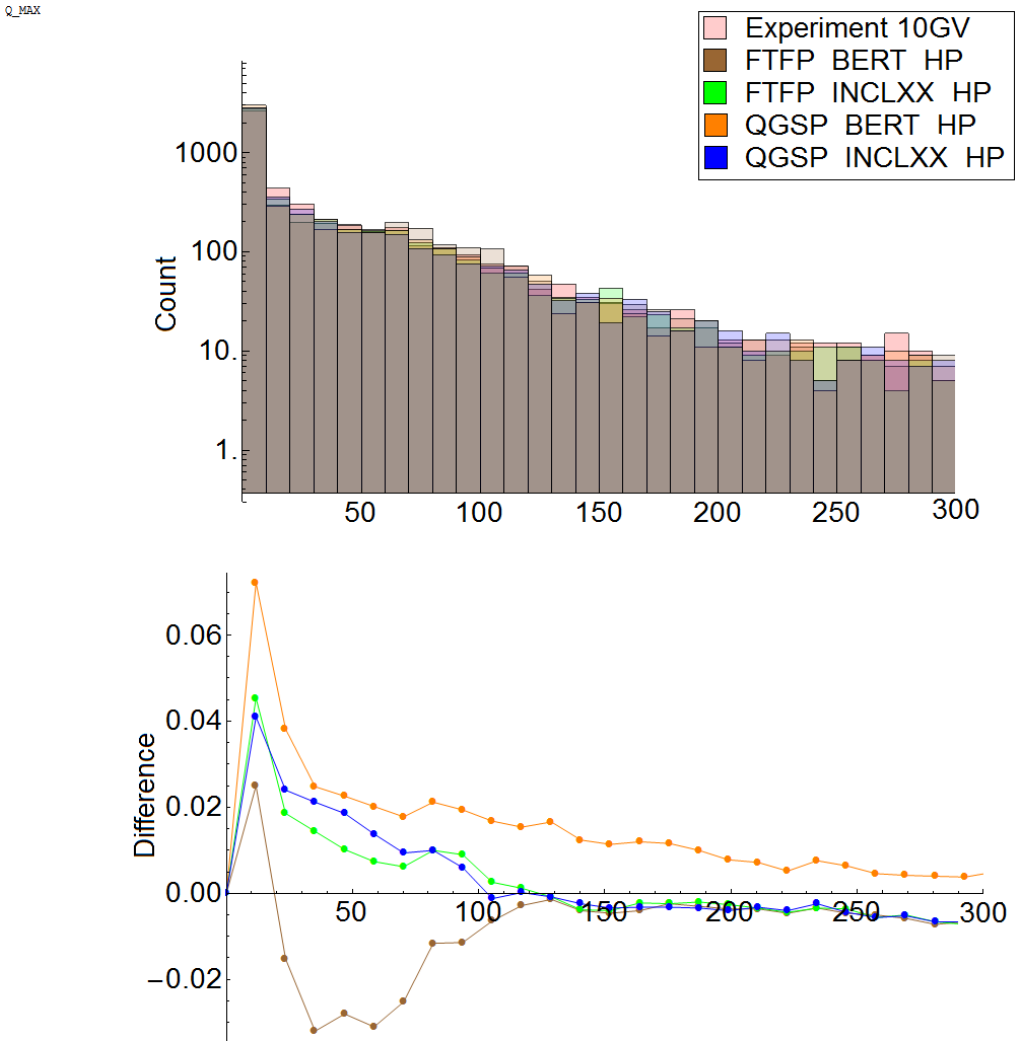
Q_{total}, $R = 50$

$N = 1300, I = 0.0533.$



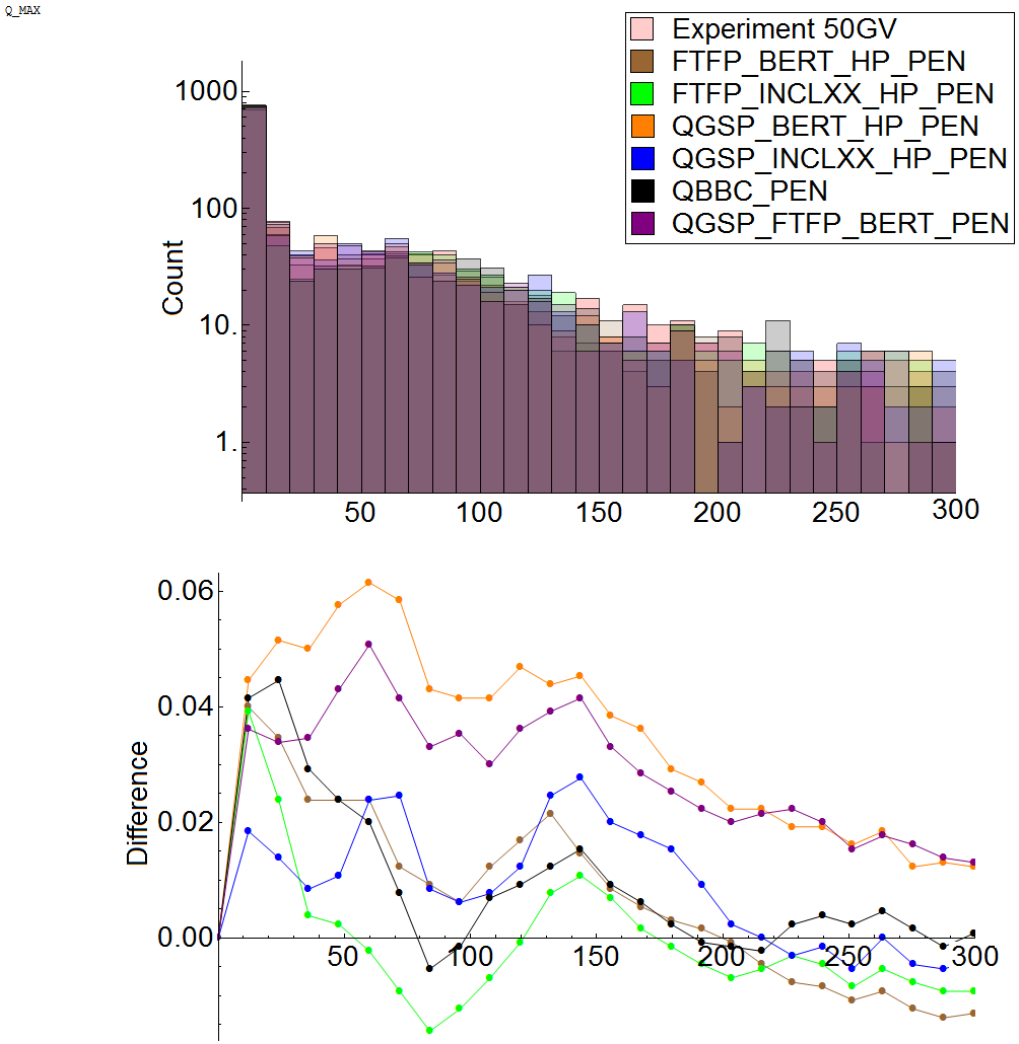
Q_{max}, $R = 10$

$N = 7500, I = 0.0222.$



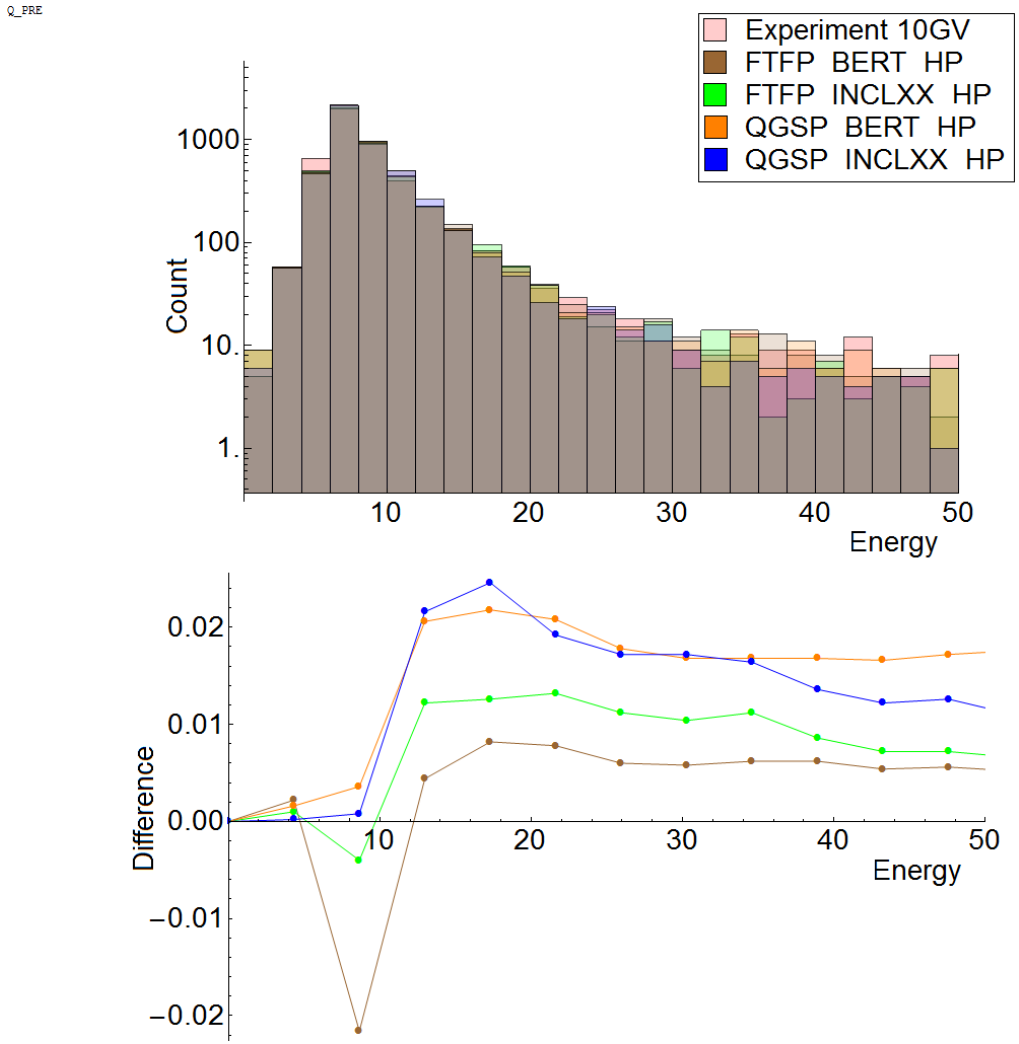
Q_{max}, $R = 50$

$N = 1300, I = 0.0533.$



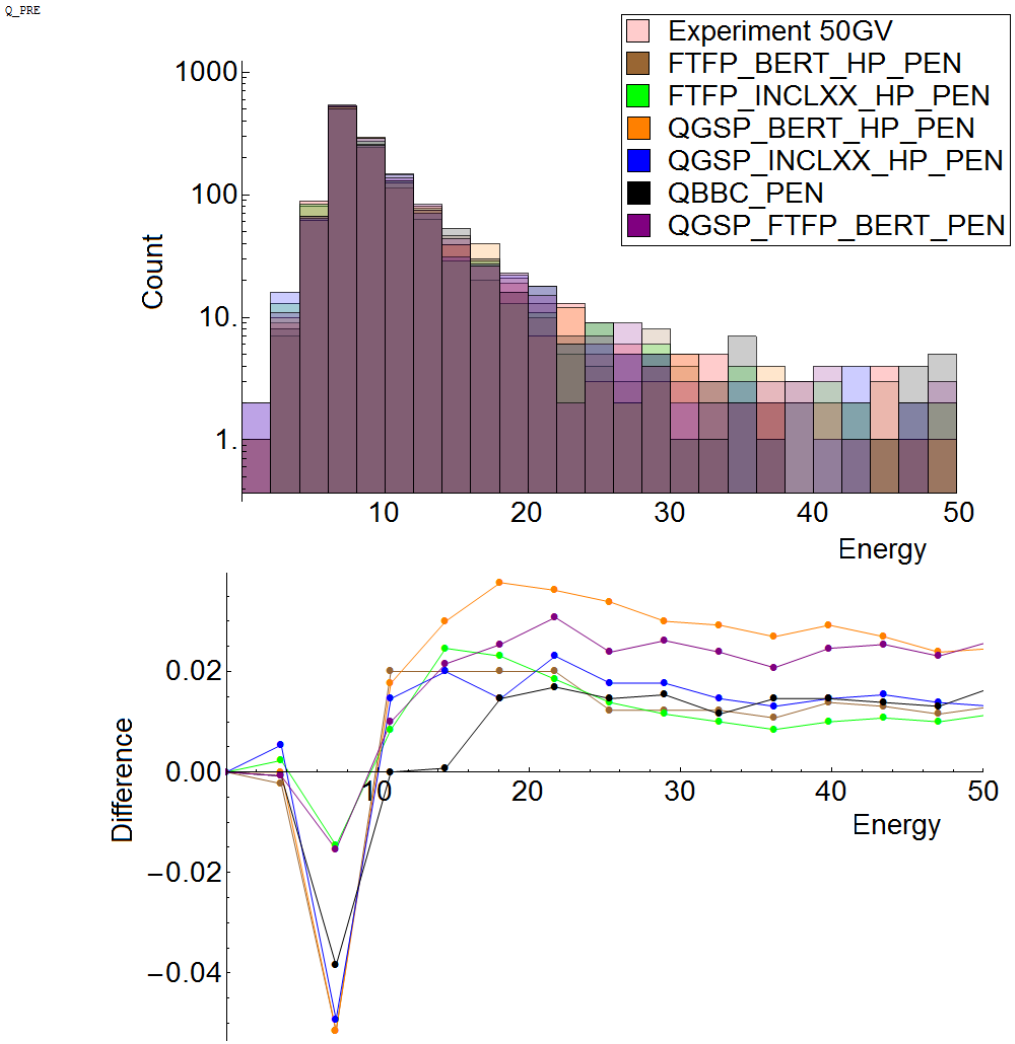
Q_{pre}, $R = 10$

$N = 7500, I = 0.0222.$



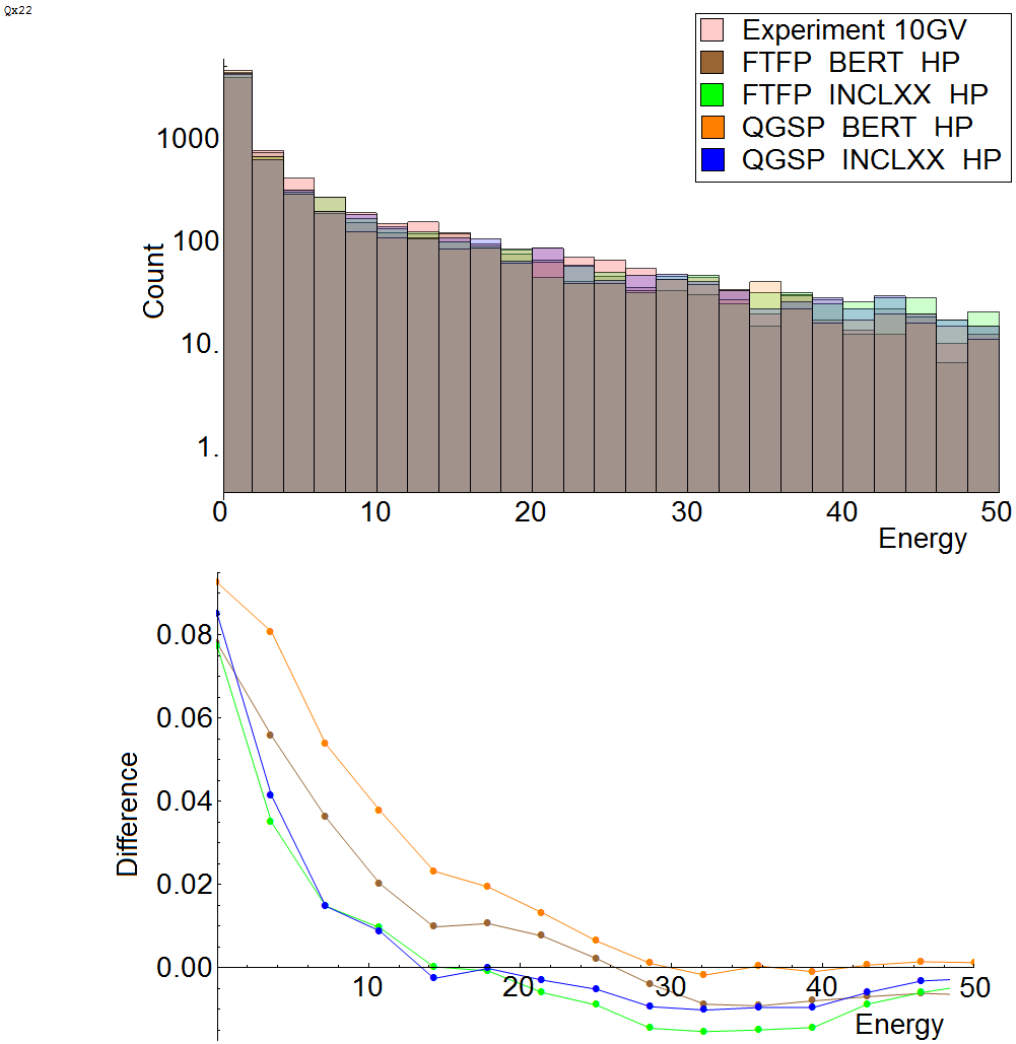
Q_{pre}, $R = 50$

$N = 1300, I = 0.0533.$



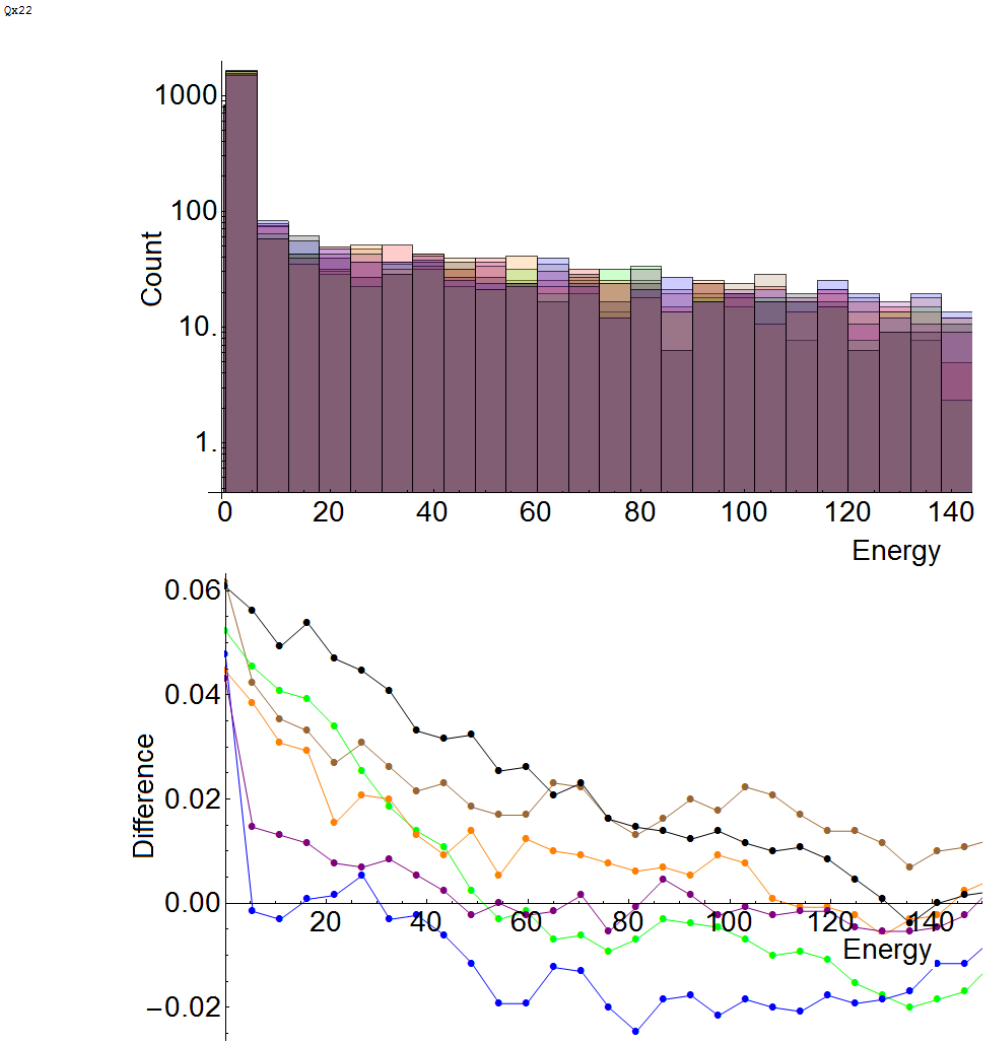
$Q_{x22}, R = 10$

$N = 7500, I = 0.0222.$



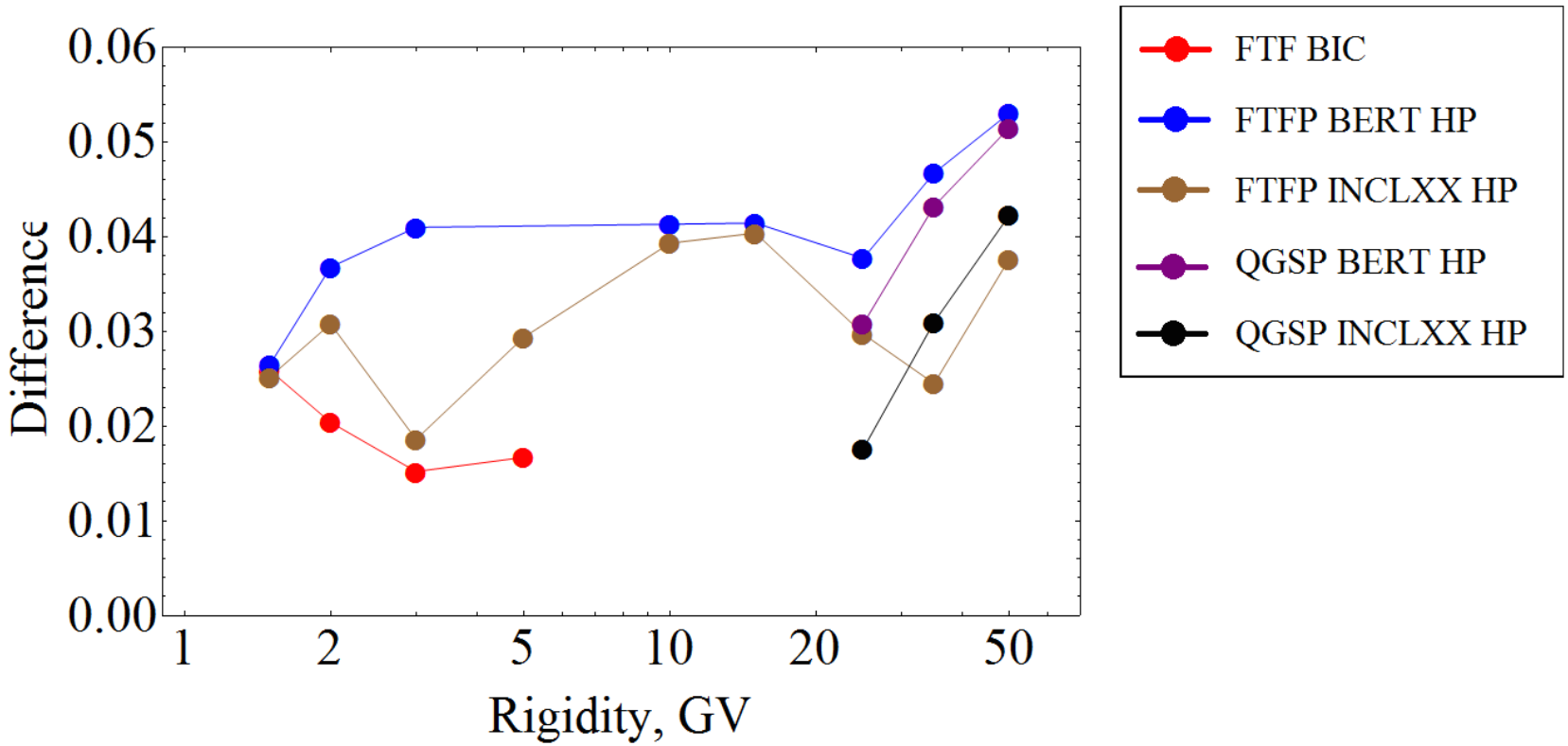
$Q_{x22}, R = 50$

$N = 1300, I = 0.0533.$

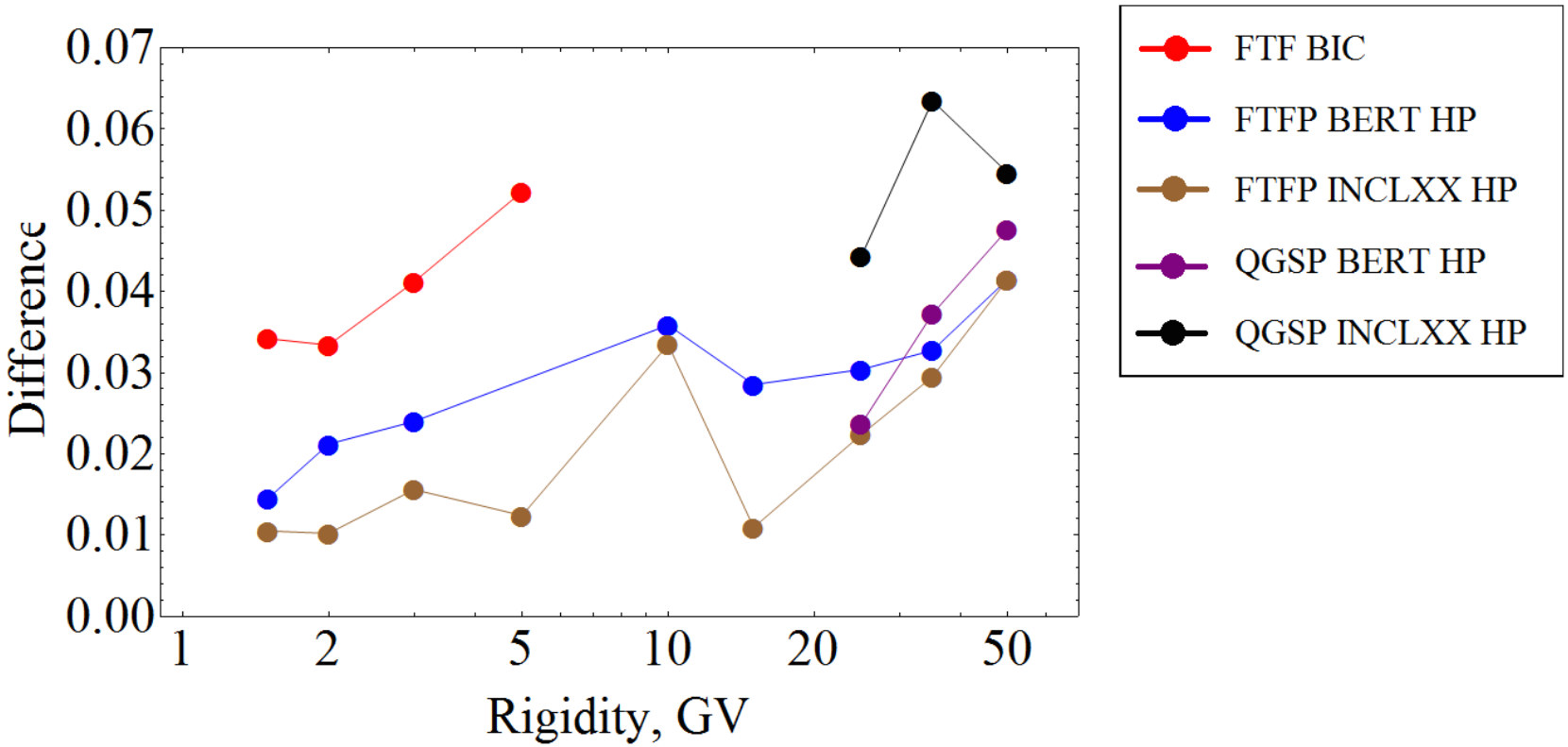


Q_{total}

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



Q_{max}


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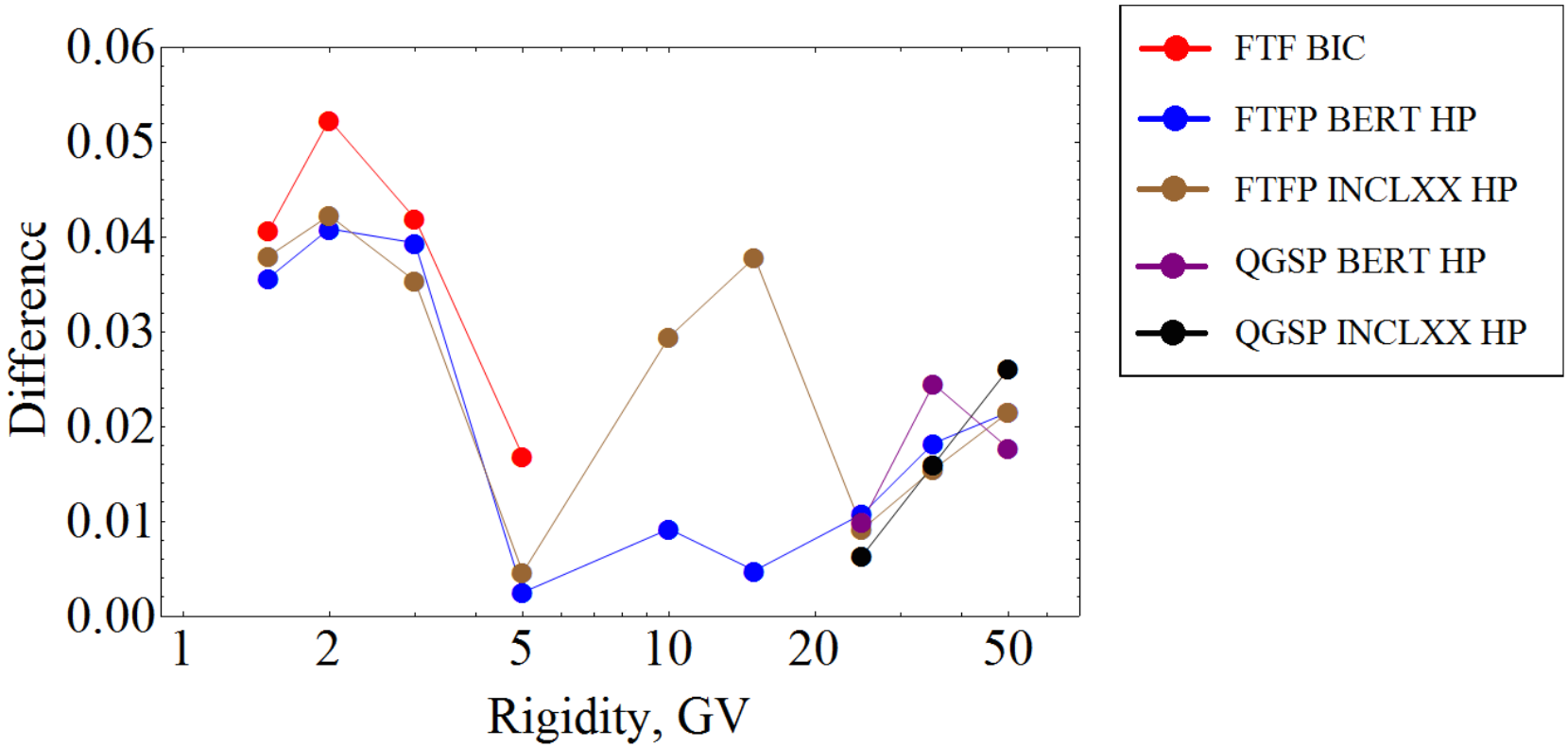
Difference
1
2
5
10
20
50
Rigidity, GV
FTF BIC
FTFP BERT HP
FTFP INCLXX HP
QGSP BERT HP
QGSP INCLXX HP

Q_{pre}


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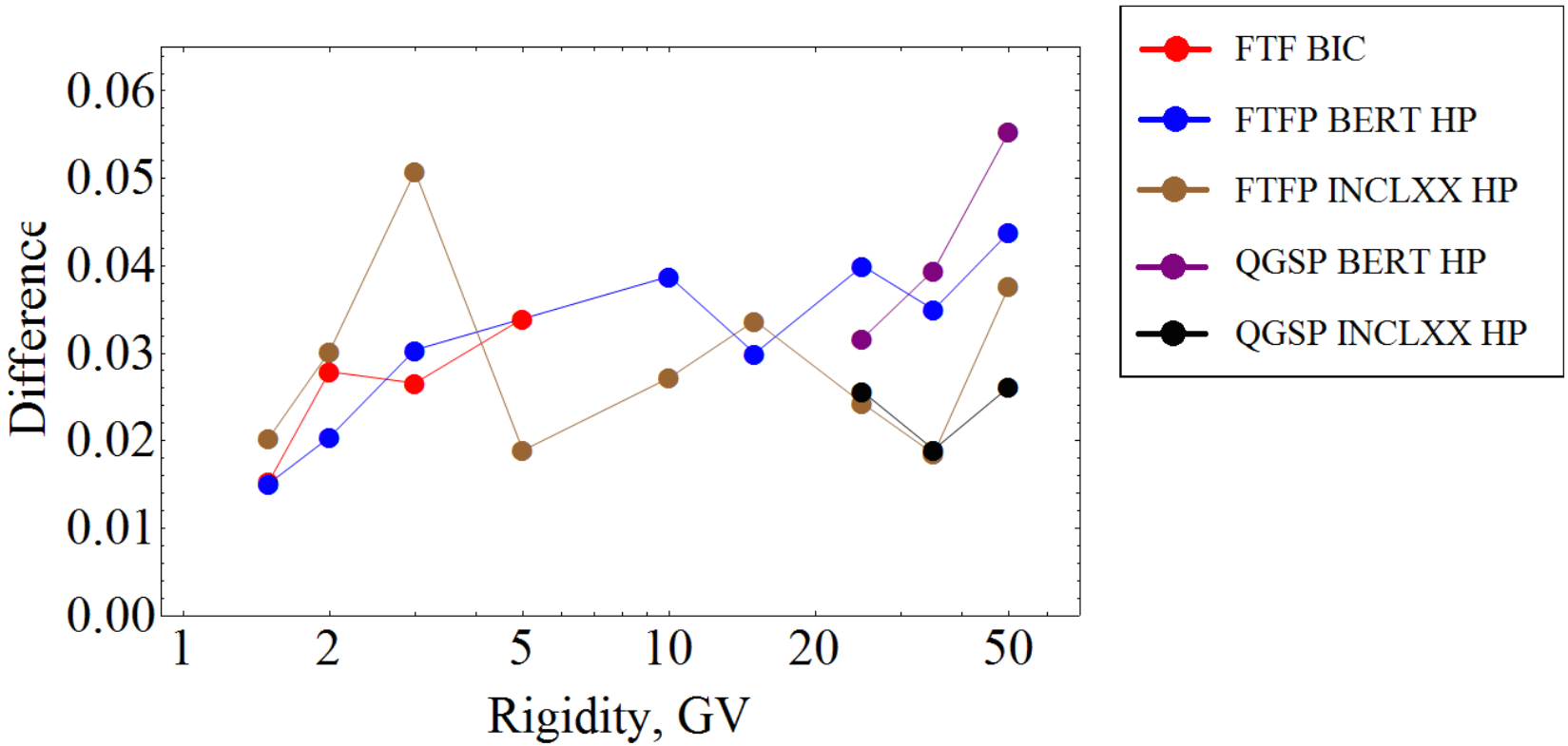
Difference
1
2
5
10
20
50
Rigidity, GV
FTF BIC
FTFP BERT HP
FTFP INCLXX HP
QGSP BERT HP
QGSP INCLXX HP

Q_{track}


Difference
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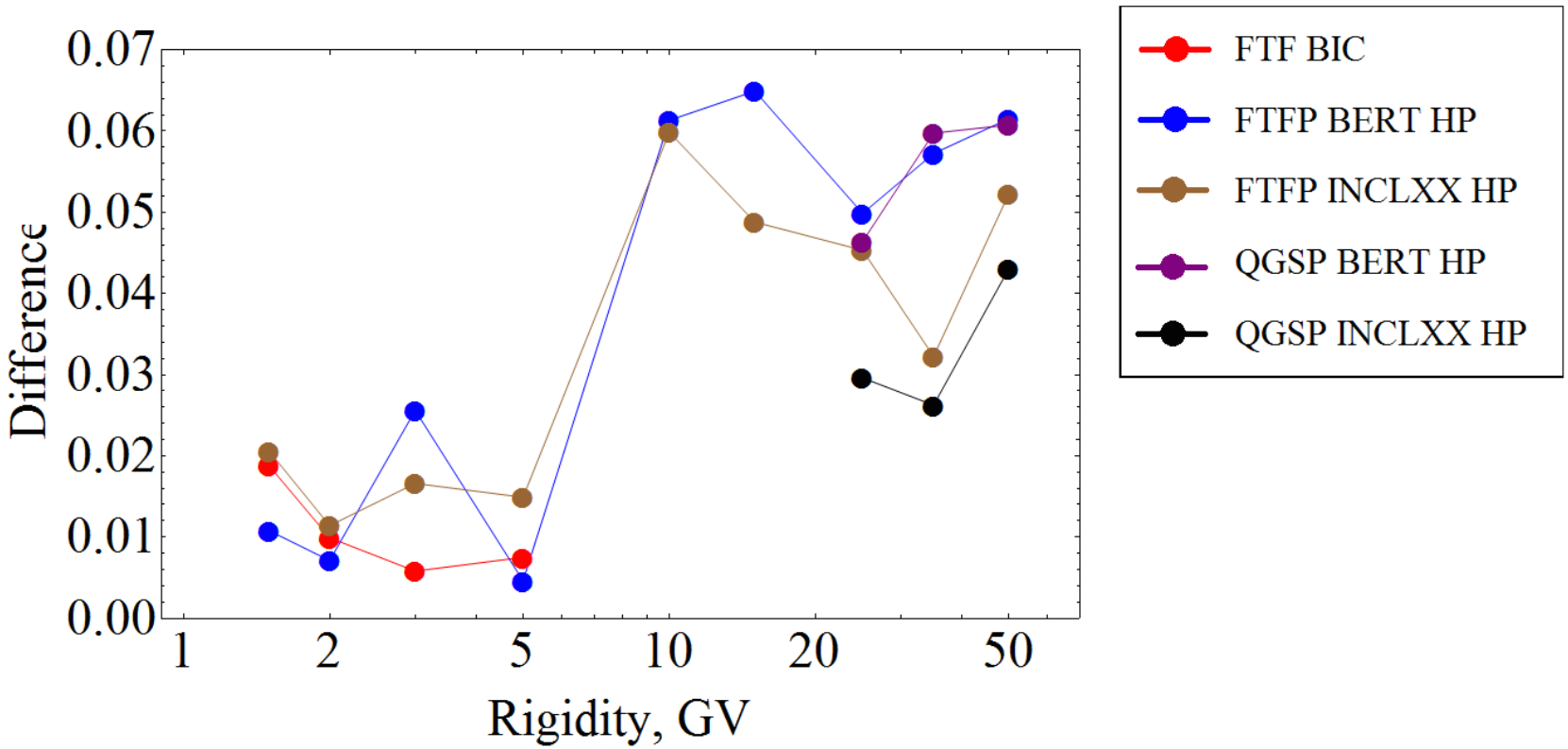
Rigidity, GV
FTF BIC
FTFP BERT HP
FTFP INCLXX HP
QGSP BERT HP
QGSP INCLXX HP

Q_{x22}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Difference
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Rigidity, GV
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QGSP BERT HP
QGSP INCLXX HP

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.*;
- 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.

We are intended to...

- increase amount of samples for precise analysis;
- preform the same analysis for low energies ($<$ 1GeV) and for high energies (up to 300..500 GeV);
- use results of investigation in particle classification problem.