Attempt to estimate the prediction power of the calorimeter properties following from different hadron models in the simulation programs; and the systematic errors of such predictions

Vasiliy L. Morgunov

DESY, Hamburg and ITEP, Moscow

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Descriptions

1. Geometry, materials:

The geometry and material description in both GEANT3 and GEANT4 as close as we could do.

2x2x2 m^3 with 80 sampling layers (2.9 cm thickness) filled with:

2 cm St–St + 5 mm scintillator + 1.5 mm fiber gap + 2.5 mm air gap .

1x1 cm scintillator cell over all calorimeter volume for hit collection.

2. Simulation procedure:

5000 π+ 10 GeV events by each program (12 programs)

GEANT4 conventional/recommended hadron physics lists:

LHEP–GN, LHEP–BE, LHEP–HP, QGSP–GN, QGSP–BE, GGSP–HP

I did not touch any parameter of all these models, they were used as it is.

See http://cmsdoc.cern.ch/ hpw/GHAD/HomePage/ for details

FLC–DET physics list includes HP, Bertini cascade between 20 MeV and 3.2 GeV , overlap with LEP from 2.8 GeV to 25 GeV and QGSP above 25 GeV; with 500 mkm range cut. FLC-DET–50 is simply 50 mkm range cut for the same hadronic physics model.

GEANT3 hadron physics – GHEISHA, FLUKA, FLUKA+MICAP, GCALOR–95.

Thanks Frank Gaede for the GEANT4 simulation program of calorimeter prototype with so many physics models in it, and easy switcher from one another.

All differences in the thresholds and cuts were reduced to the smallest values as we could do, to show the differences in the hadronic interaction models only.

GEANT3 and GEANT4 Energy and Range CUTS

To those who understand the difficulties and uncertainties of the simulation.

```
          The same for all GEANT 3 programs
            Standard TPAR for this run are
            ------------------------------
CUTGAM= 10 keV  CUTELE= 10 keV  CUTNEU= 10.00 eV
CUTHAD=  1 MeV  CUTMUO= 10 MeV
BCUTE = 10 keV  BCUTM = 10 keV
DCUTE = 10 keV  DCUTM = 10 keV  PPCUTM= 10.00 MeV
```

```
          The Global::physicsList is FLC_DET_50
                    Material : Air
 Range cuts   : gamma 50 mum   e- 50 mum  e+ 50 mum
 Energy thres : gamma 990 eV   e- 990 eV  e+ 990 eV

               Material : Iron
 Range cuts   : gamma 50 mum   e- 50 mum  e+ 50 mum
 Energy thres : gamma 4.3 keV  e- 150 keV e+ 148 keV

               Material : Polystyrene
 Range cuts   : gamma 50 mum   e- 50 mum  e+ 50 mum
 Energy thres : gamma 990 eV   e- 57 keV  e+ 57 keV

               Material : FiberGapMaterial
 Range cuts   : gamma 50 mum   e- 50 mum  e+ 50 mum
 Energy thres : gamma 990 eV   e- 38 keV  e+ 37 keV
```

```
          The Global::physicsList is
   LHEP_GN, LHEP-BE, LHEP-HP, QGSP-GN, QGSP-BE, GGSP-HP
                    Material : Air
Range cuts   : gamma 700 mum  e- 700 mum  e+ 700 mum
Energy thres : gamma 990 eV   e- 990 eV   e+ 990 eV

               Material : Iron
Range cuts   : gamma 700 mum  e- 700 mum  e+ 700 mum
Energy thres : gamma 17.1 keV e- 952 keV  e+ 907 keV

               Material : Polystyrene
Range cuts   : gamma 700 mum  e- 700 mum  e+ 700 mum
Energy thres : gamma 2.1 keV  e- 278 keV  e+ 275 keV

               Material : FiberGapMaterial
Range cuts   : gamma 700 mum  e- 700 mum  e+ 700 mum
Energy thres : gamma 1.6 keV  e- 176 keV  e+ 174 keV
```

```
          The Global::physicsList is FLC_DET
                    Material : Air
Range cuts   : gamma 500 mum  e- 500 mum  e+ 500 mum
Energy thres : gamma 990 eV   e- 990 eV   e+ 990 eV

               Material : Iron
Range cuts   : gamma 500 mum  e- 500 mum  e+ 500 mum
Energy thres : gamma 14. keV  e- 726 keV  e+ 691 keV

               Material : Polystyrene
Range cuts   : gamma 500 mum  e- 500 mum  e+ 500 mum
Energy thres : gamma 1.8 keV  e- 226 keV  e+ 220 keV

               Material : FiberGapMaterial
Range cuts   : gamma 500 mum  e- 500 mum  e+ 500 mum
Energy thres : gamma 1.4 keV  e- 145 keV  e+ 141 keV
```

GEANT 3, additional information

```
 ***************************************************
 **  You are requesting the GEANT-FLUKA interface:  **
 **  for conditions and warnings see the comments   **
 **  in GUPHAD/GUHADR and/or the GEANT manual.      **
 ***************************************************
```

GEANT Material Parameters				MICAP Material Parameters			
Material	No/Iso	A	Z	A	Z	Density	Coll.Len
Scint....	17/ 1	6.2	3	6.0	3	0.8286E-02	0.940E+02
	17/ 2	-	-	7.0	3	0.8168E-01	0.796E+01
Fiber-gap	22/ 1	6.2	3	6.0	3	0.4015E-02	0.194E+03
	22/ 2	-	-	7.0	3	0.3957E-01	0.164E+02
St-Steel.	21/ 1	55.8	26	55.8	26	0.5921E-01	0.327E+01
	21/ 2	58.7	28	58.7	28	0.7921E-02	0.349E+02
	21/ 3	52.0	24	52.0	24	0.1780E-01	0.184E+02
AIR.....	15/ 1	14.6	7	14.0	7	0.4967E-04	0.846E+04

Density in (Atoms/barn/cm)
Collision Length for 1 MeV neutron in (cm)

```
 ***************************************************
 *                                                 *
 *    GEANT - CALOR Interface  Version  1.03/08    *
 *    ----------------------------------------     *
 *        13. 1.95  C.Zeitnitz, T.A.Gabriel        *
 *                                                 *
 *     NMTC is used for hadronic interactions of   *
 *        protons,neutrons and charged pions       *
 *   up to 3.5 GeV (proton,neutron), 2.5 GeV(pion) *
 *                                                 *
 *    A Scaling Model is used for the energy range *
 *                 up to 10 GeV.                   *
 *                                                 *
 *      MICAP is calculating the interaction of    *
 *       Neutrons with an energy below 20 MeV      *
 *                                                 *
 *   For interactions of hadrons not implemented in *
 *        CALOR or with an energy above 10 GeV     *
 *                 FLUKA is called                 *
 *                                                 *
 *  The transport of electrons, positrons and gammas *
 *                 is done by GEANT                *
 *                                                 *
 ***************************************************
 *        Neutron cutoff energy=   10.     eV      *
 ***************************************************
```

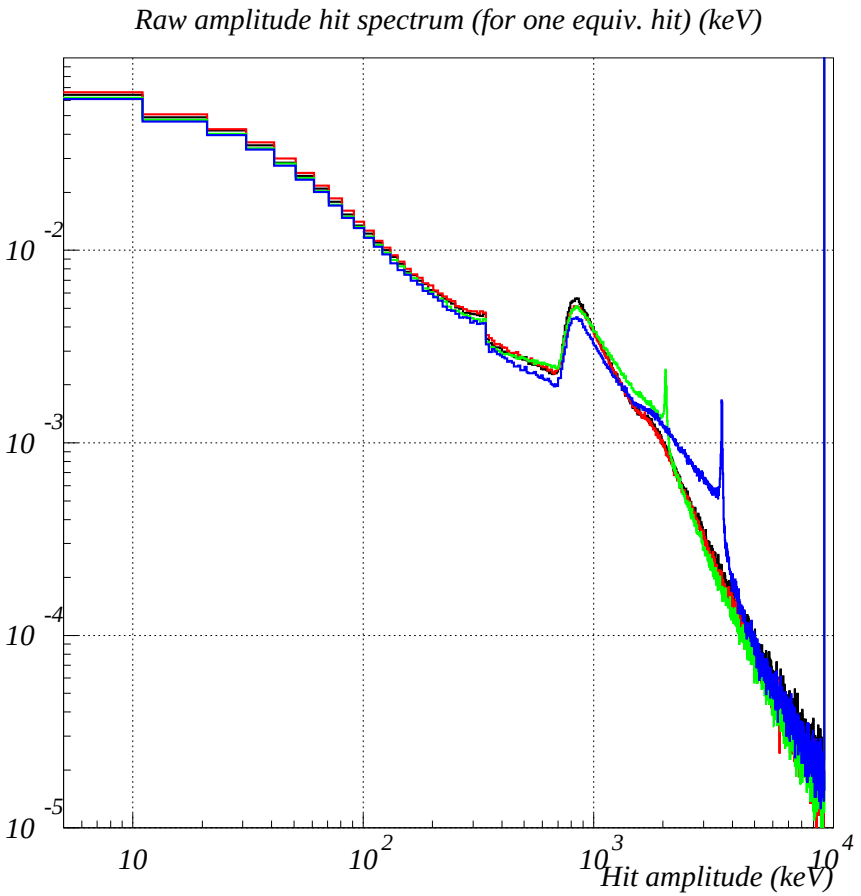
Some explanations

Each hadron physics model has two entry points:

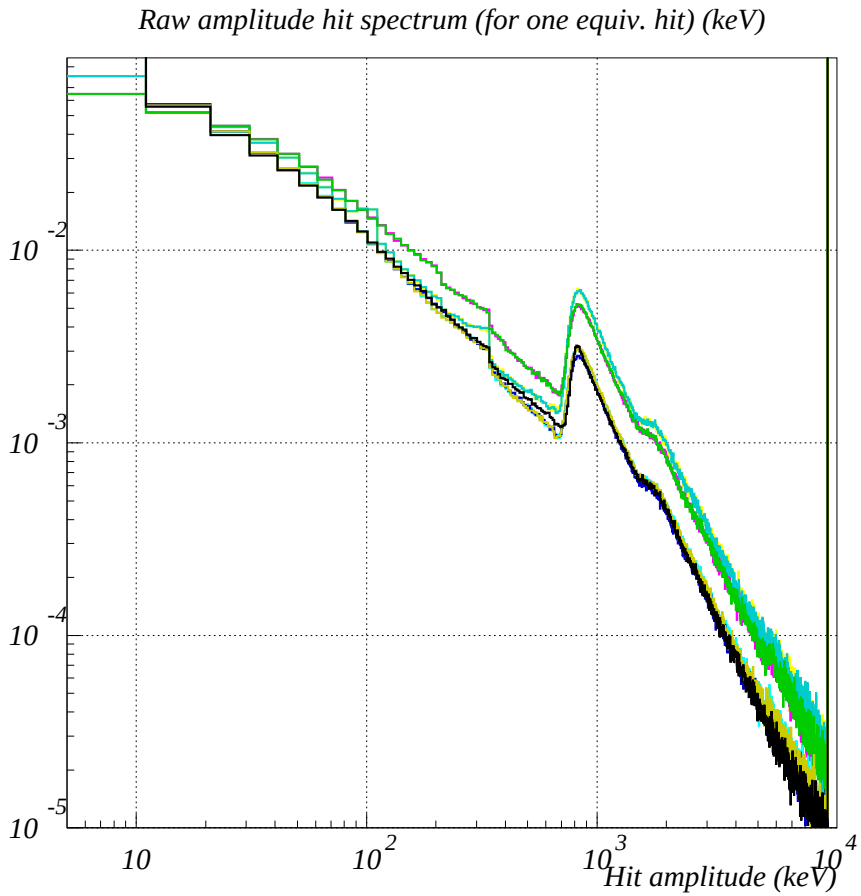
1. It predict the cross–section for the particular particle, energy and material. This cross–section is used in the tracking procedure to define the point of the interaction and the model that should proceed the hadronic interaction at this point.

2. After that, the particular model called at the point with particle type, energy, and element of material as parameters to simulate one hadronic interaction (at the output one has secondaries in the stack).

Raw amplitude spectrum, π+ 10 GeV

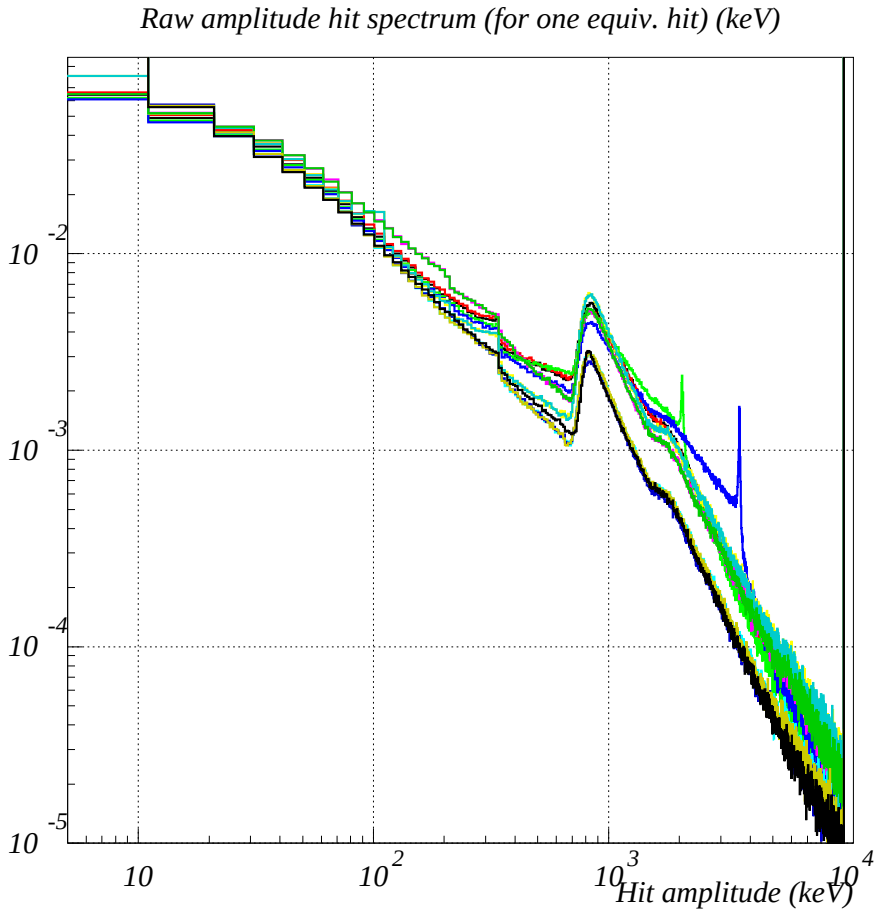


GEANT 3 only



GEANT 4 only

Raw amplitude spectrum, all together π+ 10 GeV

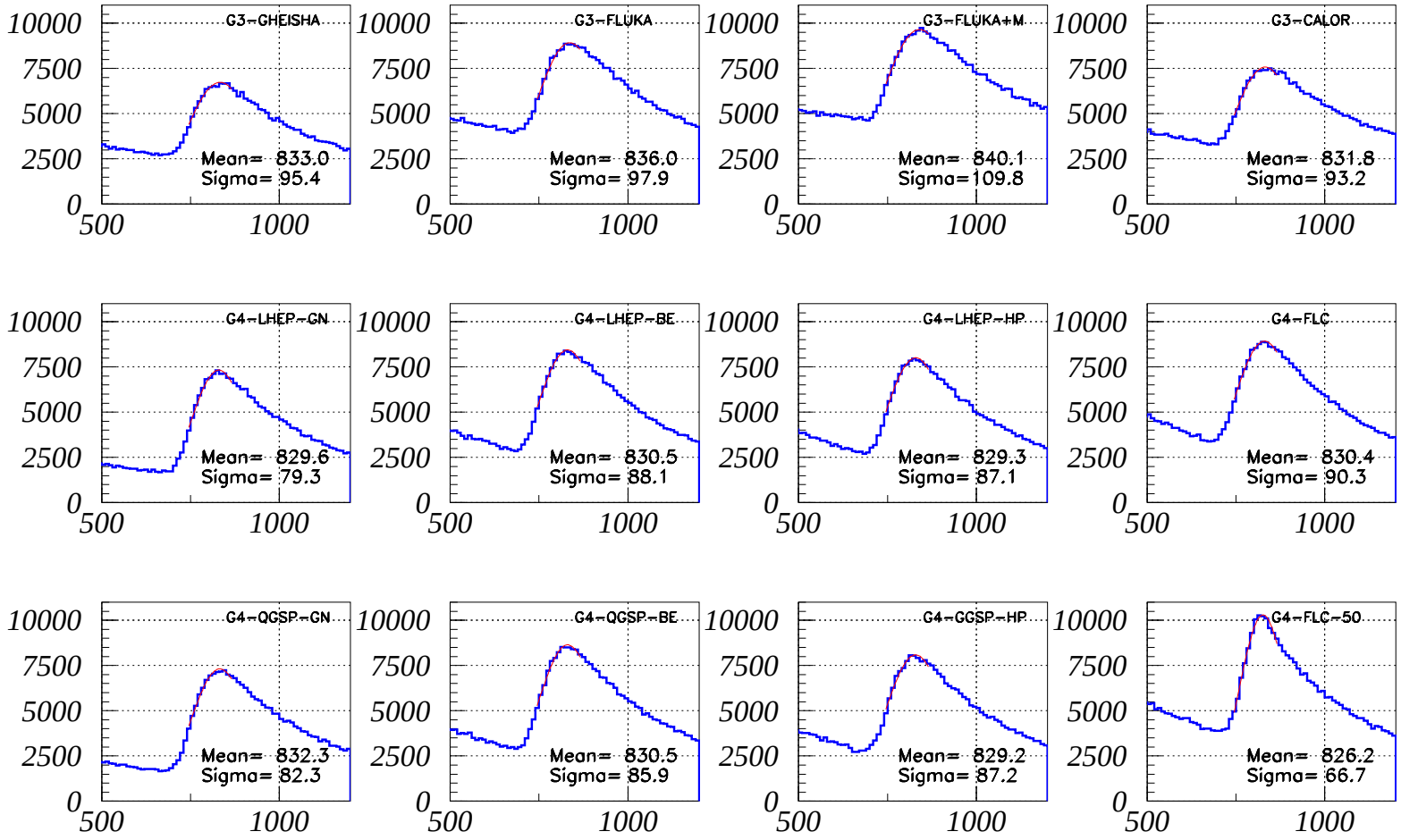


All programs show similar spectrum below the MIP peak that is low energy component comes from absorber to the scintillator. It will be cut by discriminator at the 500 keV of visible energy.

(maybe ???) MICAP code is responsible for strange spikes at about 2 and 4 MeV of raw amplitude, this peak maybe be connected with neutron elastic scattering on the scintillator protons; or with some gamma line from n,gamma reactions on the Iron nuclei.

MIP peak close view, π+ 10 GeV

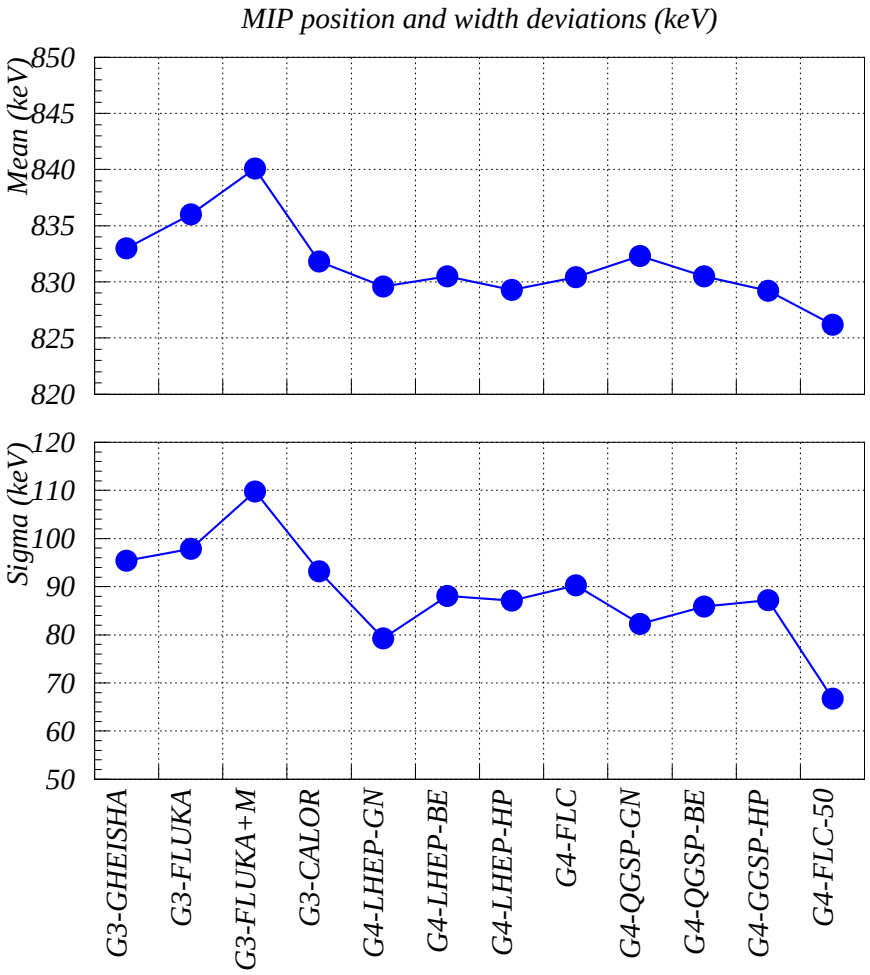
MIP pick position, close view (keV)



Discriminator threshold was set at the 500 keV of visible energy for all runs to get more realistic data.

For the 50 mkm range cut MIP peak is more narrow than all others (???).

MIP peak position, π+ 10 GeV

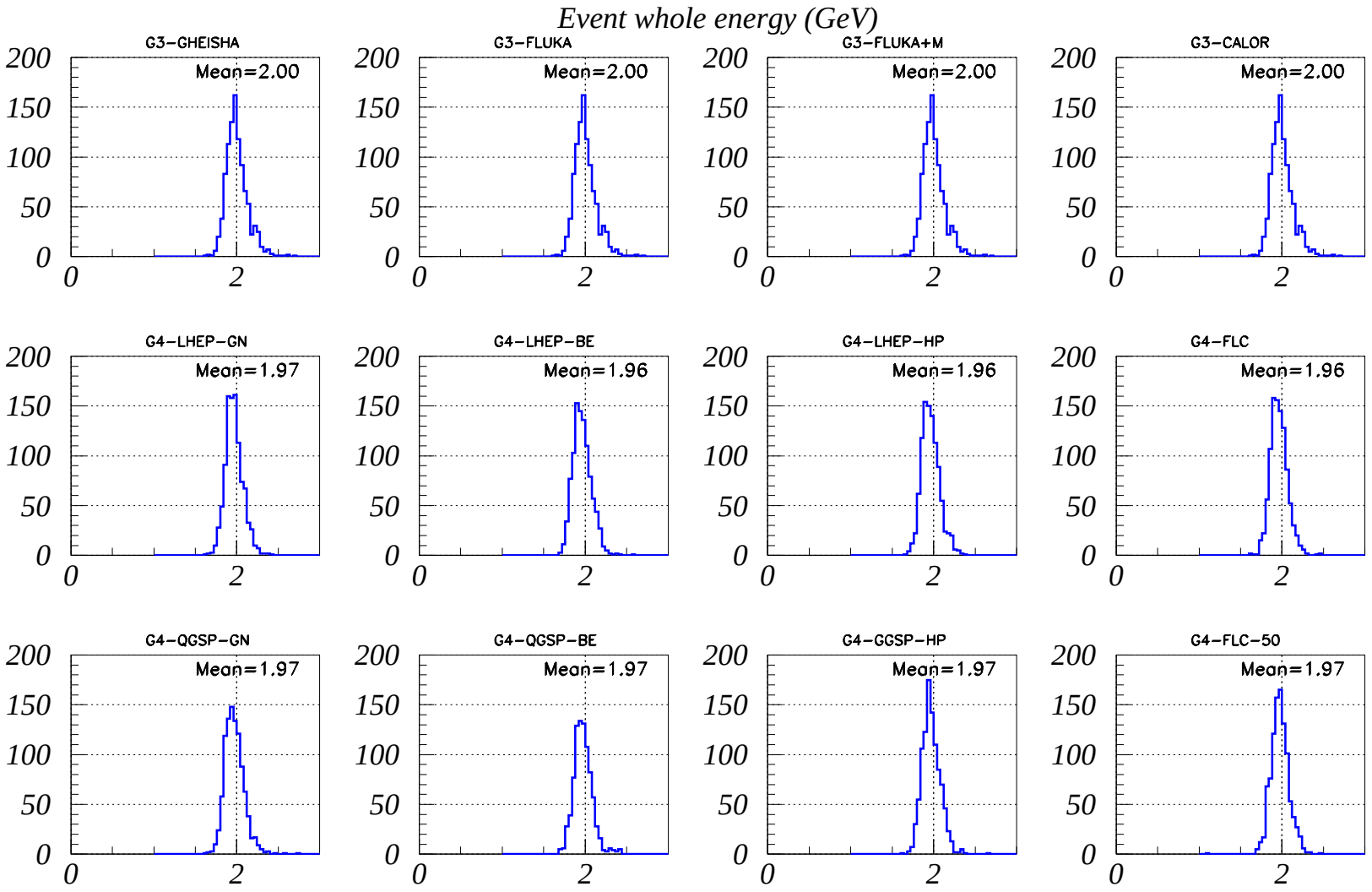


The MIP peak positions are pretty close for all programs, (840–828 keV; $\pm$1.6 %).

Let us take an average value to get a conversion factor from E_{vis} to E_{phys} from 2 GeV muon run (full absorption).

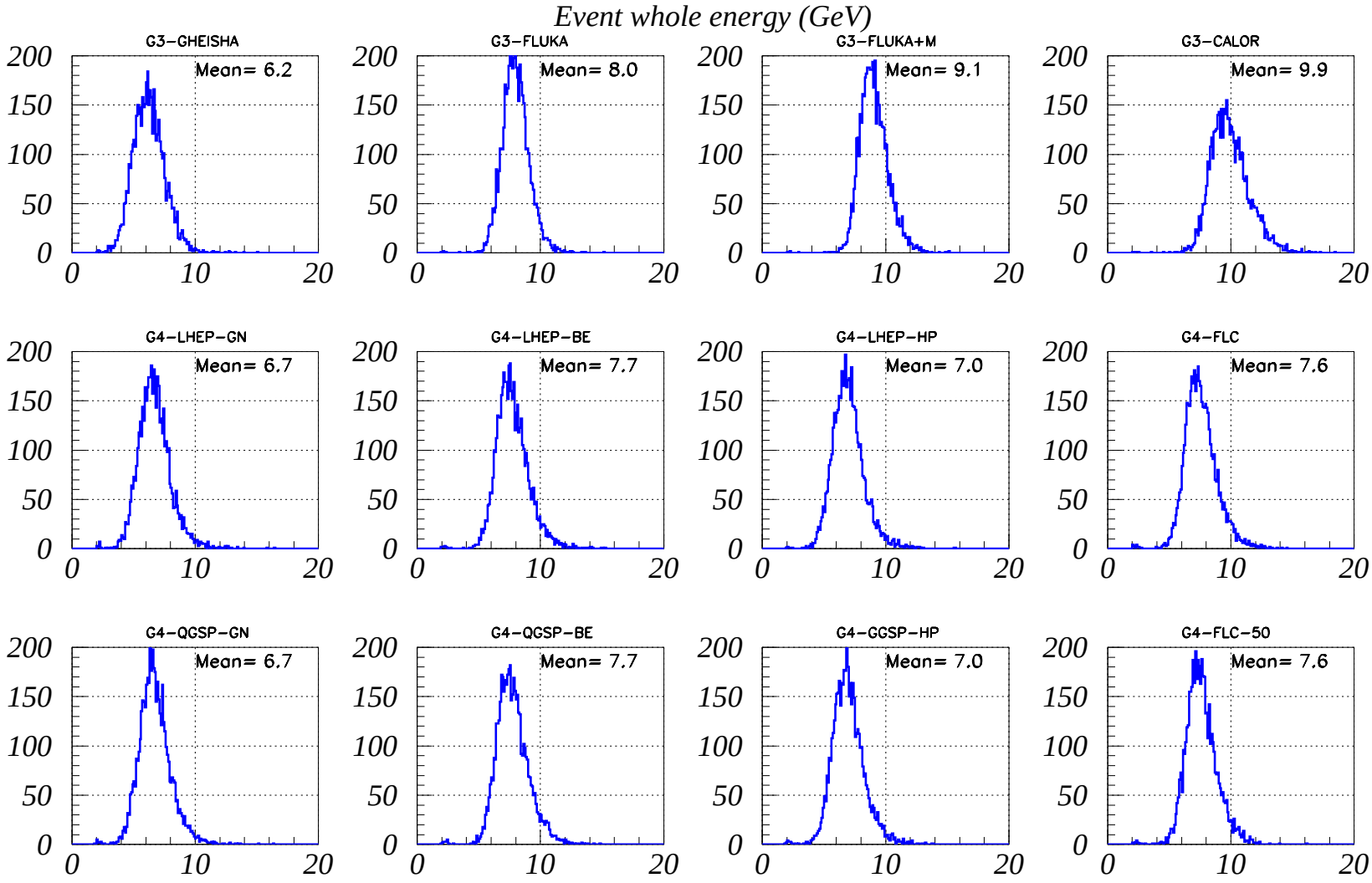
That is close to the realistic test–beam procedure.

Whole energy spectrum, μ- 2 GeV



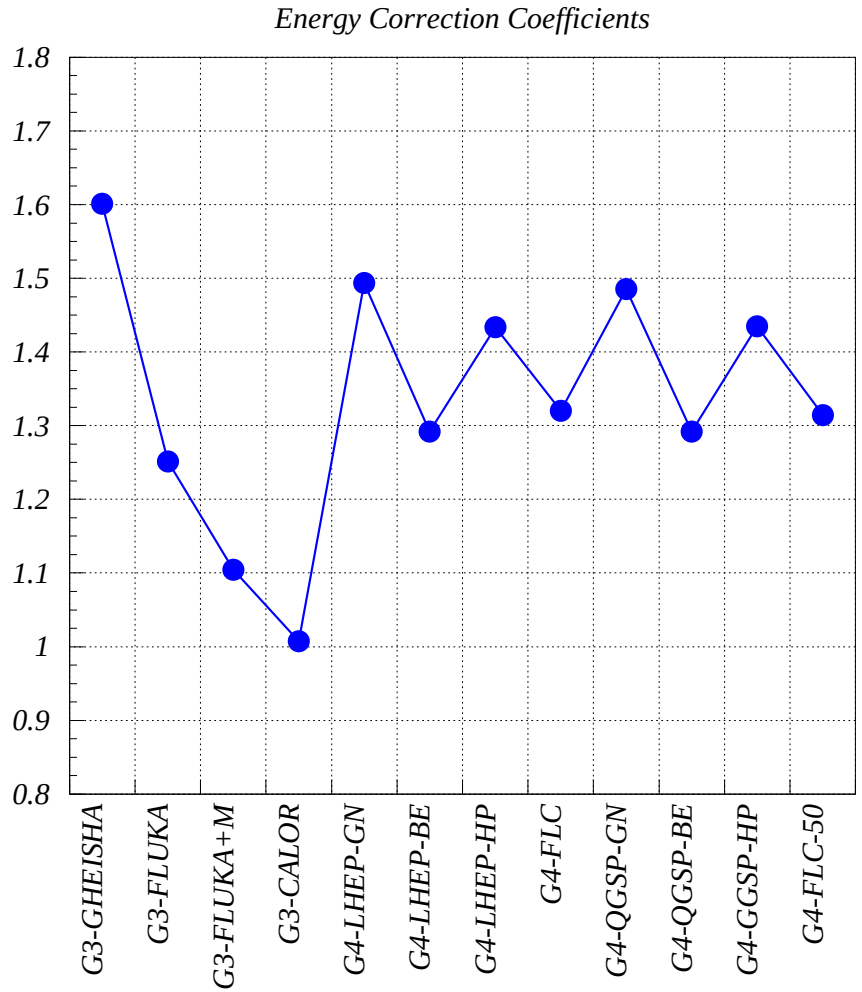
One sampling factor = 25.15 gives us the reconstructed muon energy with spread of about 3%.

Whole energy spectrum, π+ 10 GeV



Visible energy multiplied by sampling factor 25.15. $\longrightarrow$ Another calibration factors are needed.

Energy correction factors, π+ 10 GeV

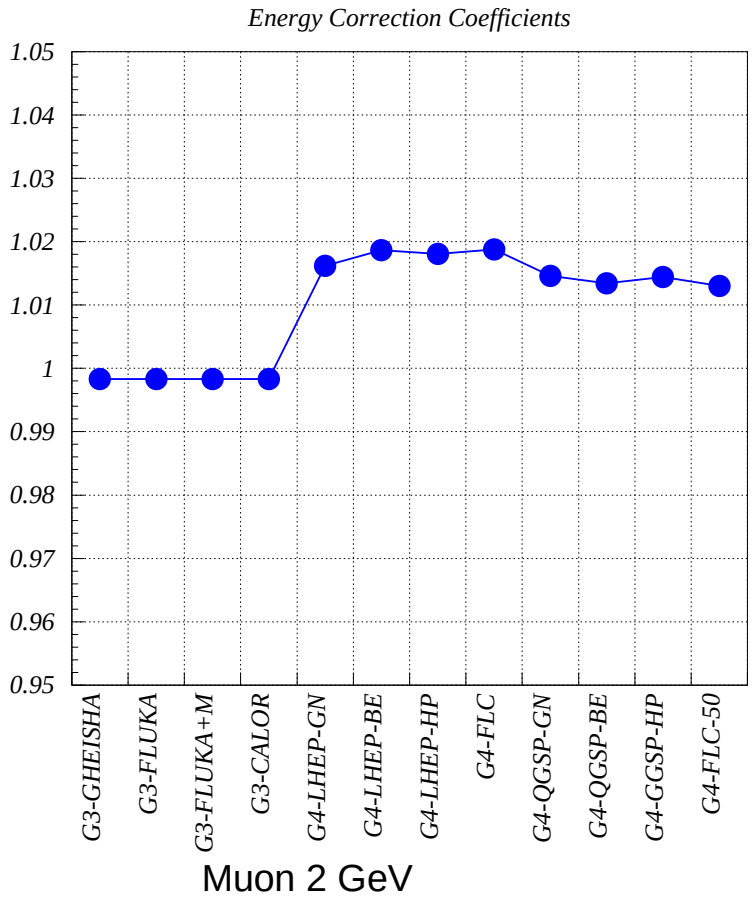


The spread is rather big.

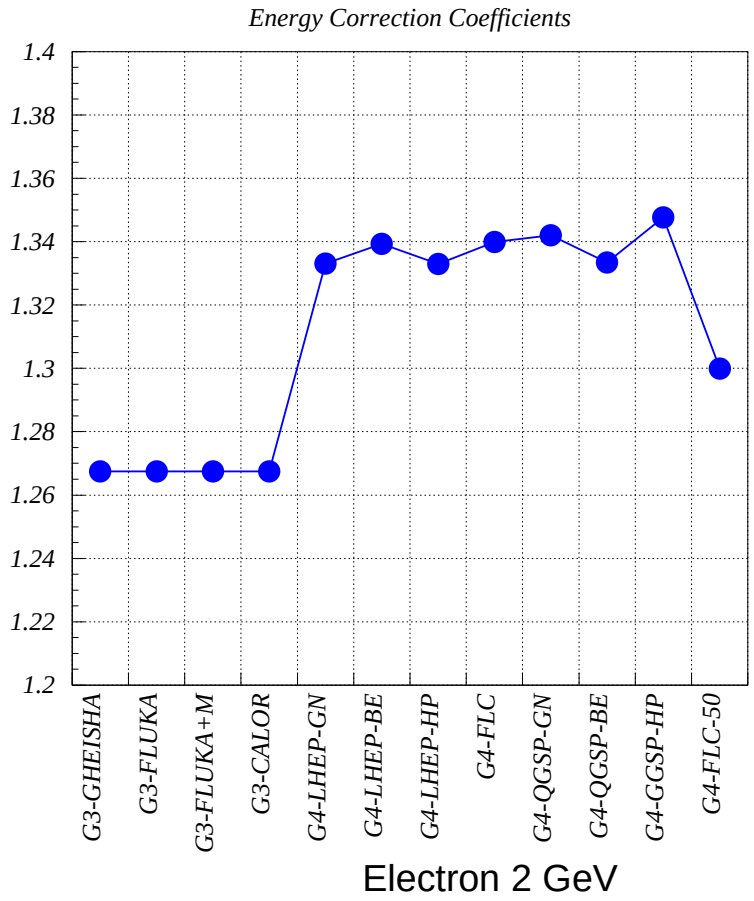
Only GCALOR is close to the beam energy, all others simulate significantly less energy with the same sampling fraction factor taken from muon run.

Let us look at μ and e energy correction factors.

Energy correction factors, μ- and e-



Muon 2 GeV

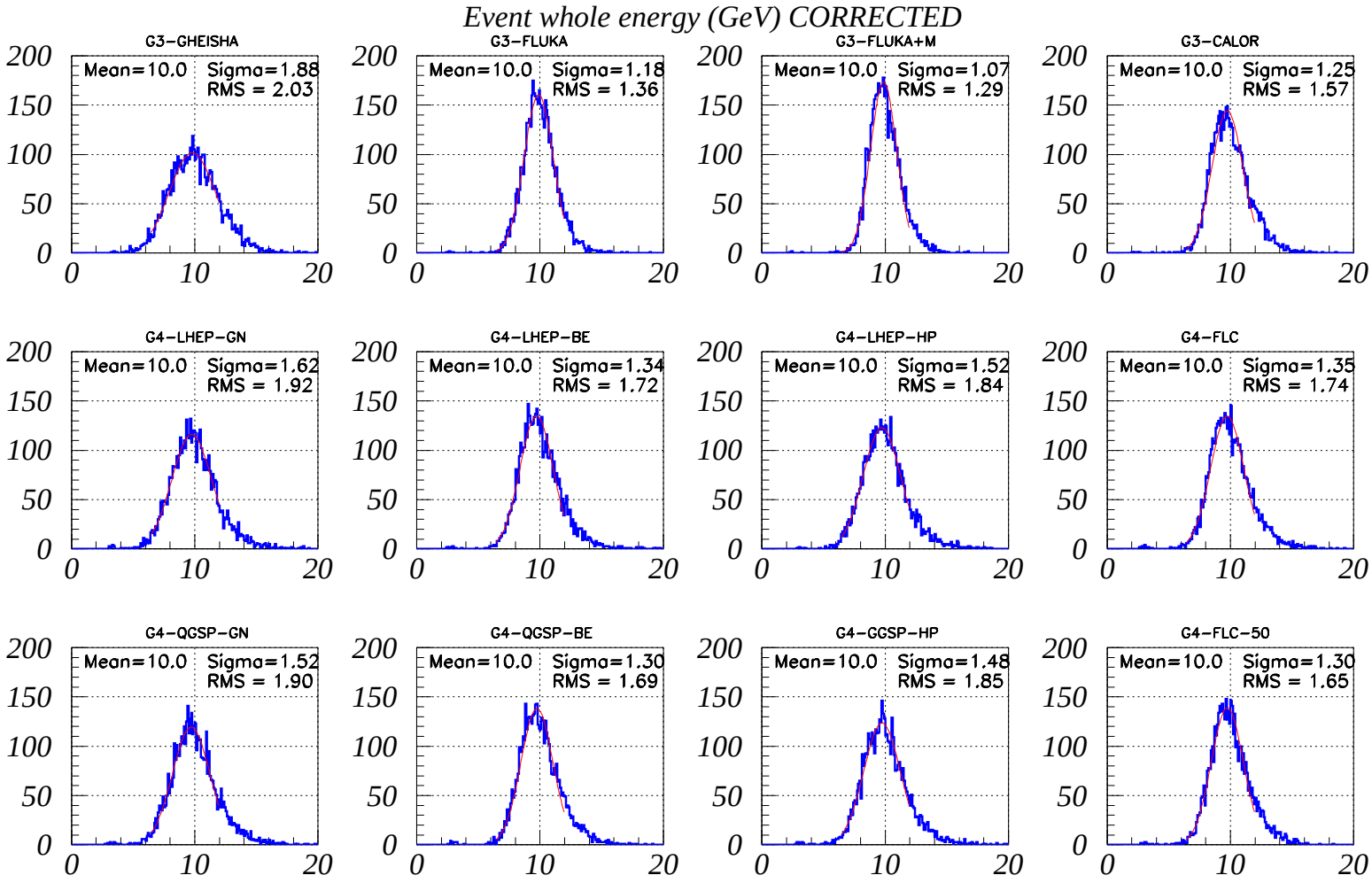


Electron 2 GeV

Here is the effect of range cutting clear visible for FLC model with 500 mkm and 50 mkm range cuts ($\approx$ 3% in amplitude correction).

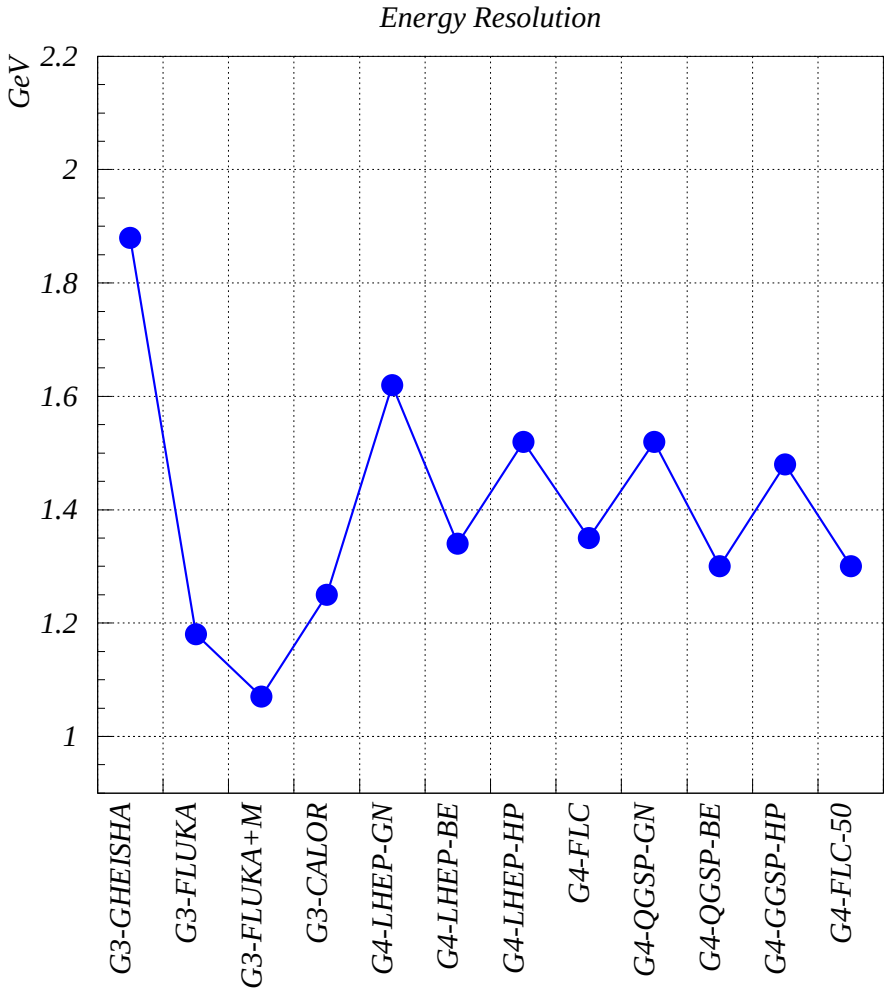
As it is also visible, better take electromagnetic scale for energy calibration in GEANT4 models to get better absolute calibration.

Corrected energy spectrum, π+ 10 GeV



Visible energy multiplied by sampling factor 25.15 and by additional individual correction factor

Calorimeter energy resolution, π 10+ GeV



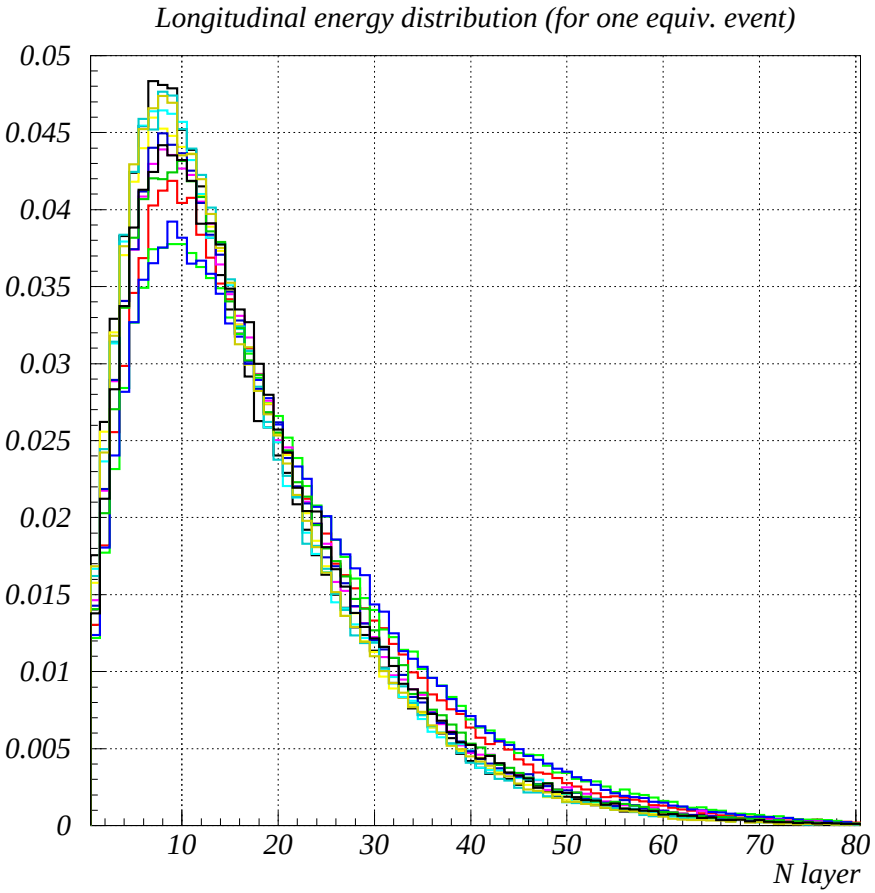
The spread is about of factor two for GEANT3 and order of 20% for GEANT4 models.

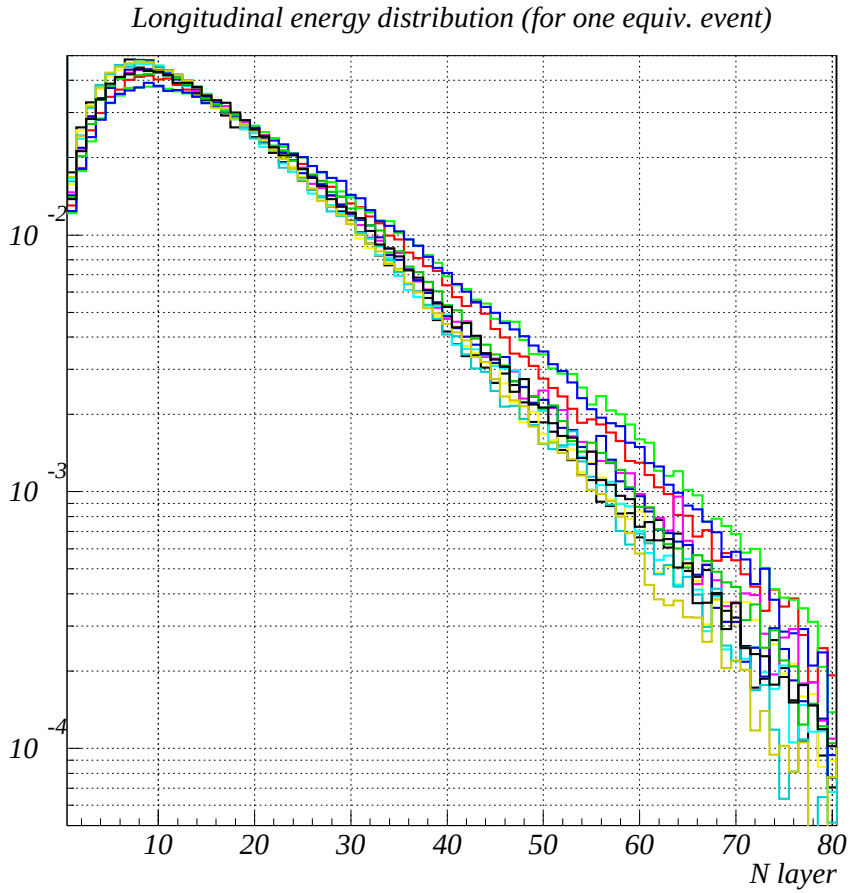
Bertini intranuclear cascade gives systematically better resolution, that is close to GCALOR model with the spread from 1.25 to 1.35 GeV; that is not bad.

The tree of four GEANT3 physics give the spread in energy resolution between 1.07 – 1.25 GeV; that is also not bad.

By the way, the Bertini cascade was written in 70'y of last century.

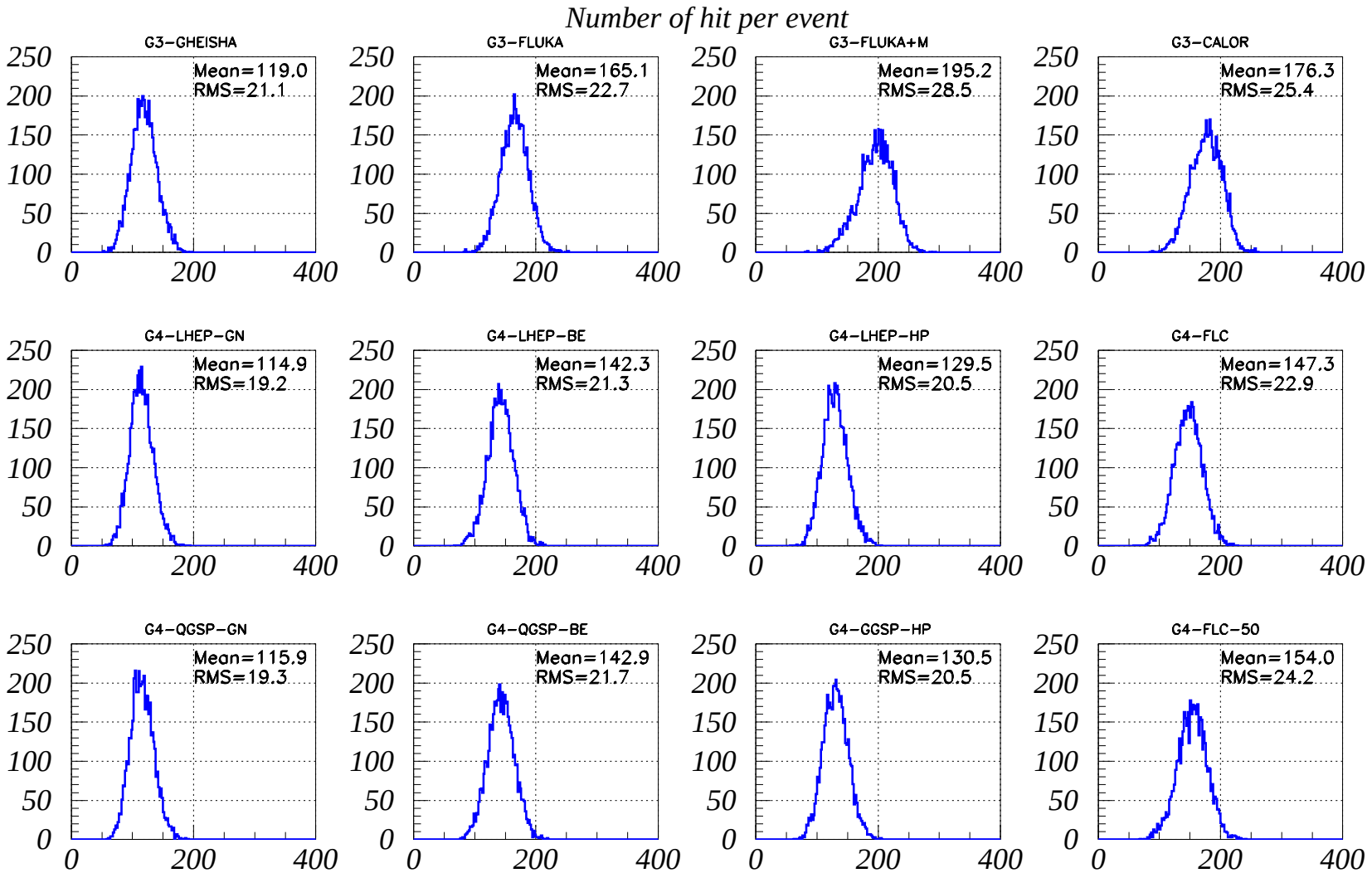
Longitudinal energy distribution, π+ 10 GeV





All 12 models – the spread is not so large as it would be.

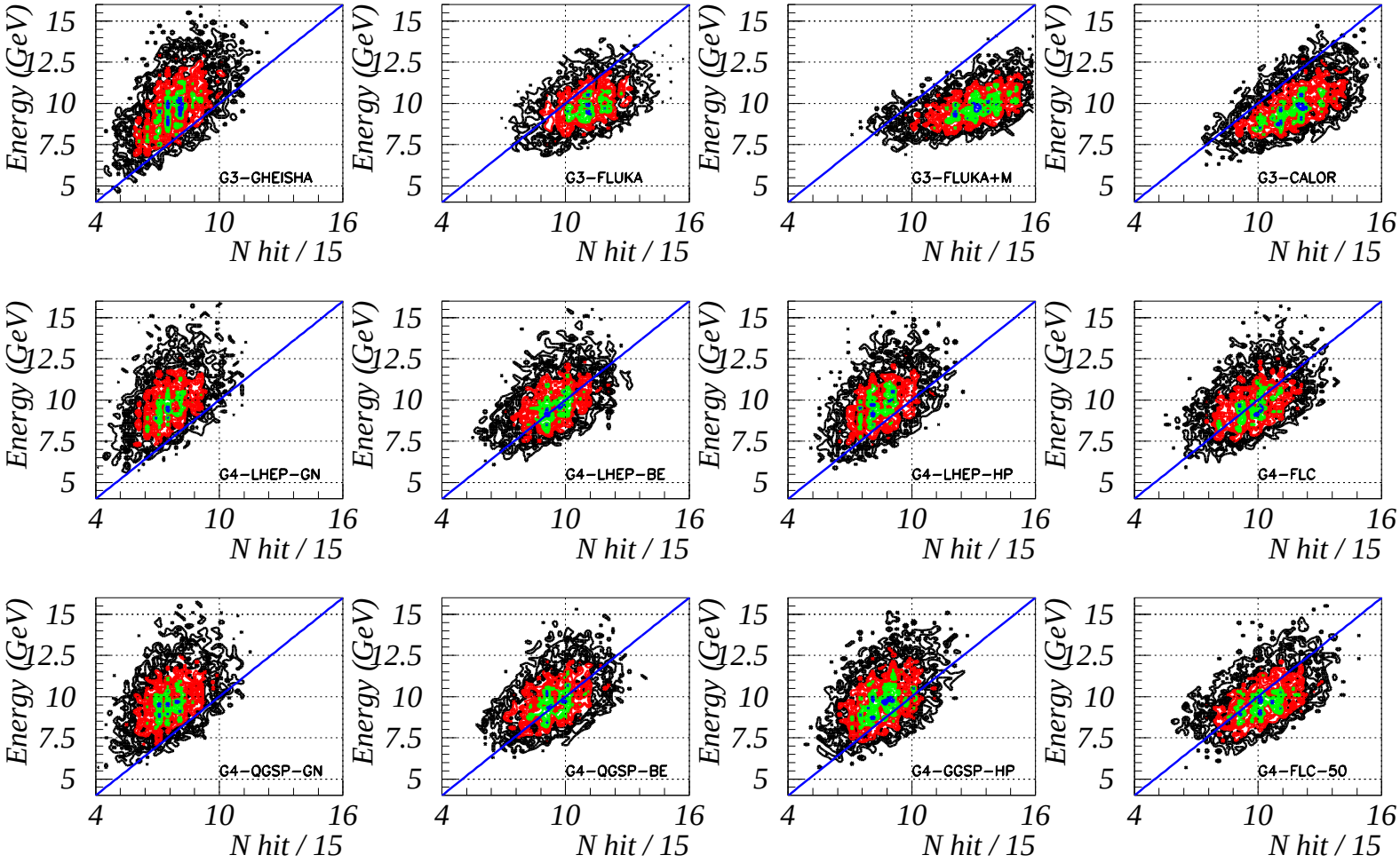
Hit number per event, π+ 10 GeV



The spread is from 115 to 195 – almost twice.

Event energy VS Number of hits π+ 10 GeV

Correlation between corrected energy and number of hits/15

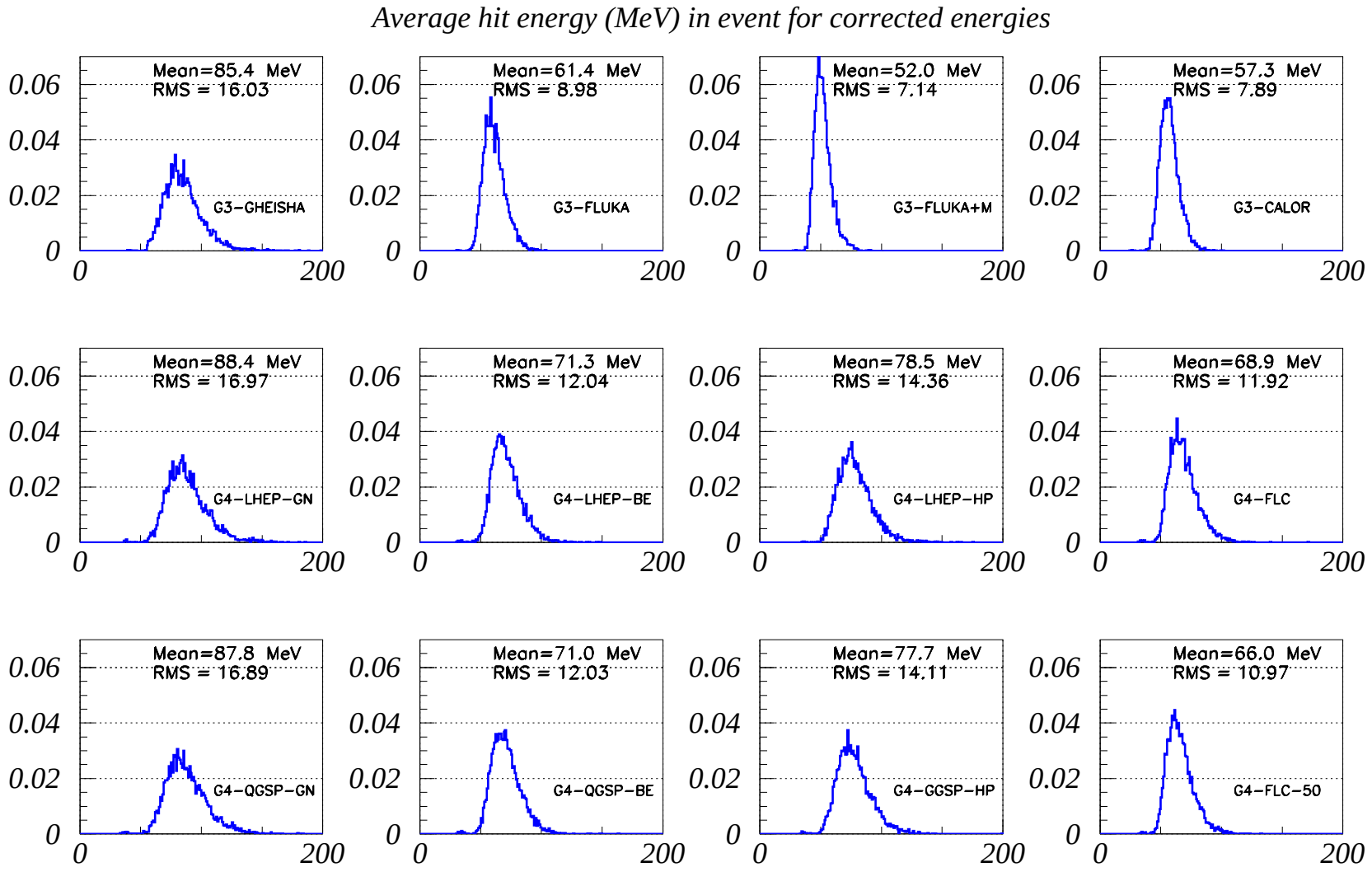


Remark: In the case of FLUKA+MICAP energy is less correlated with the number of hits in event;

and that is the reason it gives better energy resolution.

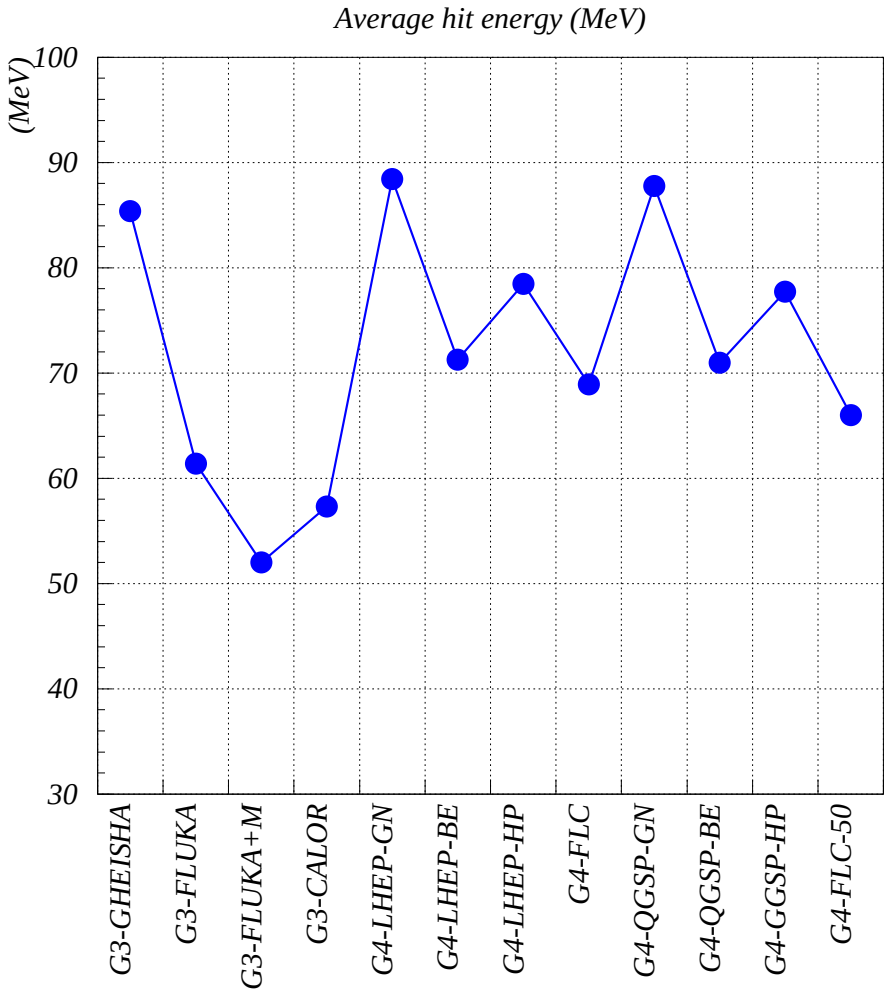
Such a kind of dependences is important for understanding of digital calorimeter simulation.

Average hit energy, π+ 10 GeV



The spread is from 52 to 88 MeV/hit and a big difference in shapes.

Average hit energy, π 10 GeV

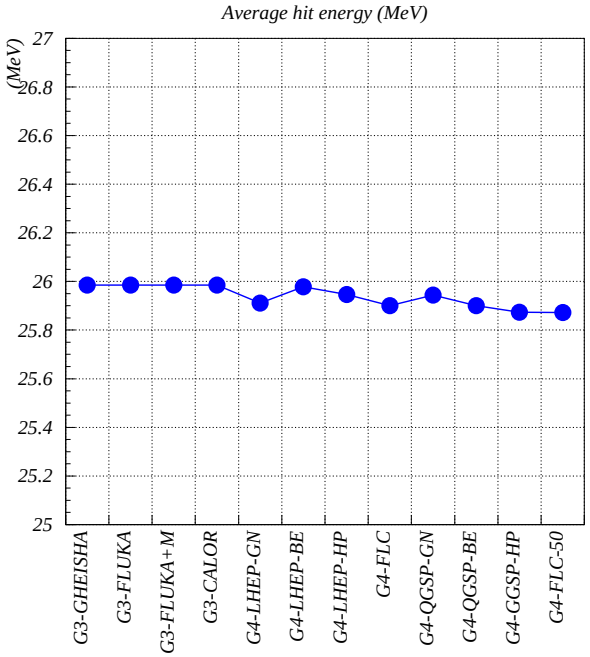


All GHEISHA's are in agreement,

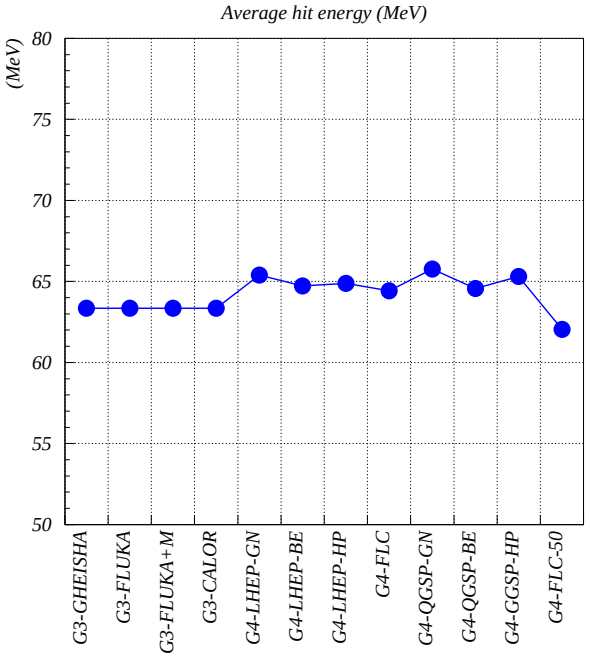
as all Bertini's in GEANT4

FLUKA and CALOR give significantly less hit density.

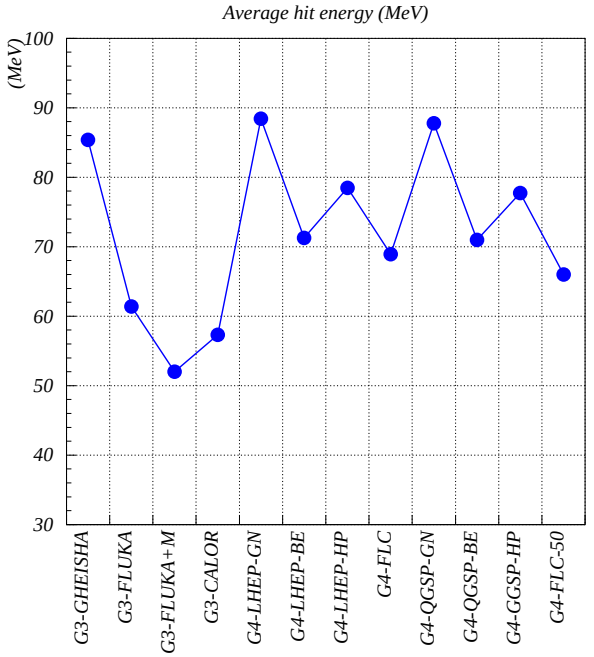
Average hit energy, ALL



Muon 2 GeV

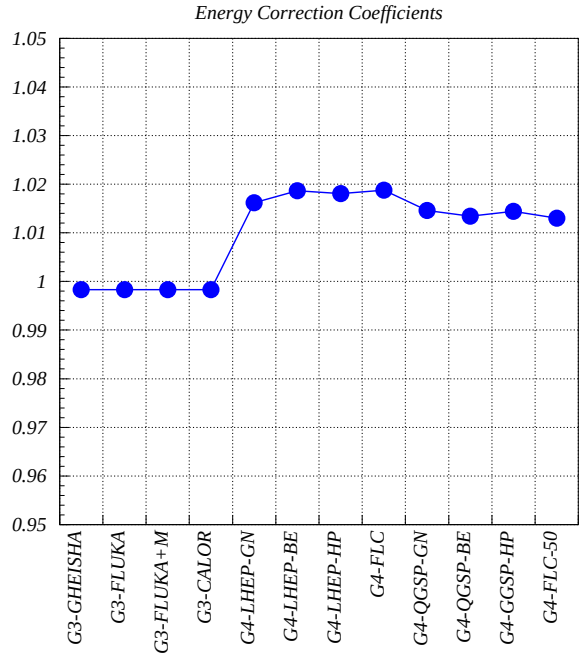


Electron 2 GeV

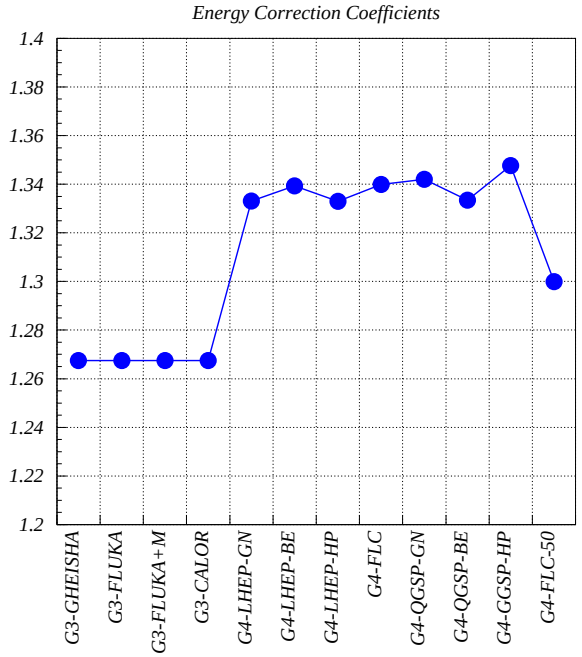


Pion + 10 GeV

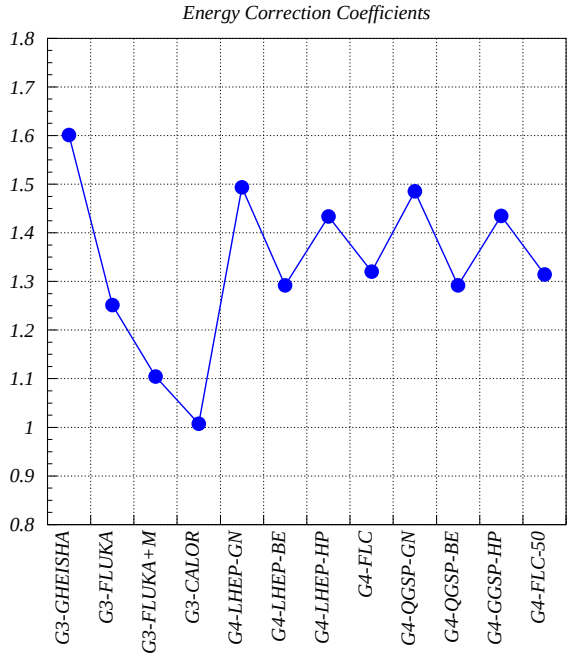
Energy correction factor, ALL



Muon 2 GeV

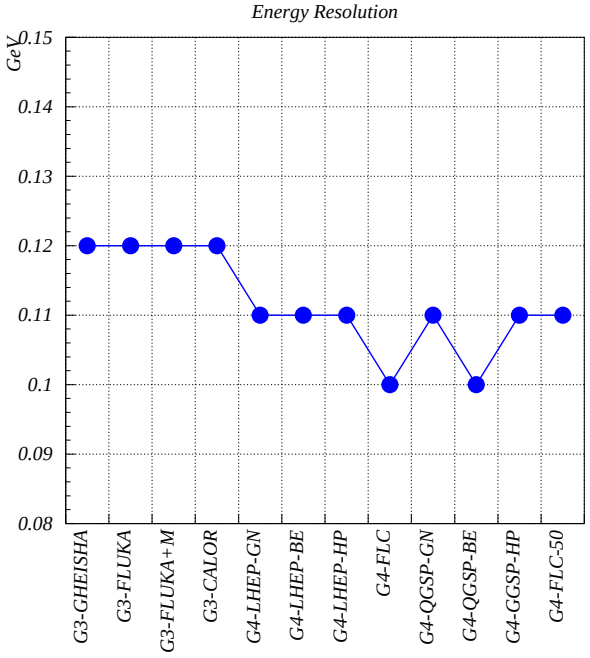


Electron 2 GeV

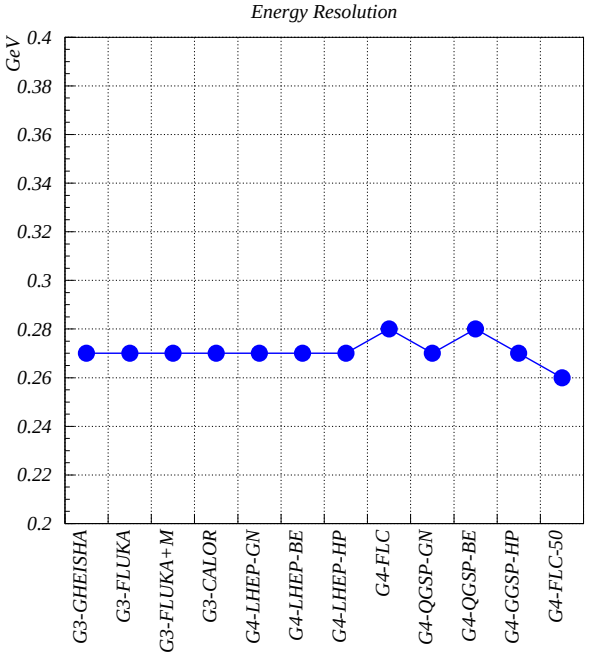


Pion + 10 GeV

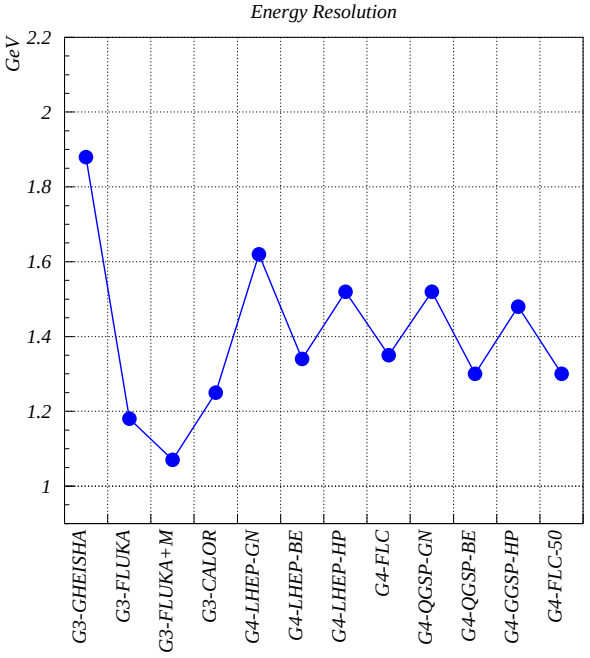
Calorimeter energy resolution, ALL



Muon 2 GeV



Electron 2 GeV



Pion + 10 GeV

Reconstruction in brief

All calculations are based on the modified adaptive 3–D physical clustering program

with threshold = 500 keV of raw energy of cell.

Cluster finding algorithm can recognize several types of clusters, such as:

- Track-like (piece of track)
- Mixture of the hadron tracks; (few hadron tracks that are too close to one another)
- Electromagnetic showers inside the hadronic cascade; (π^0 originated);
- Neutron originated hits or clusters (mainly low energy neutron elastic scattering on proton)

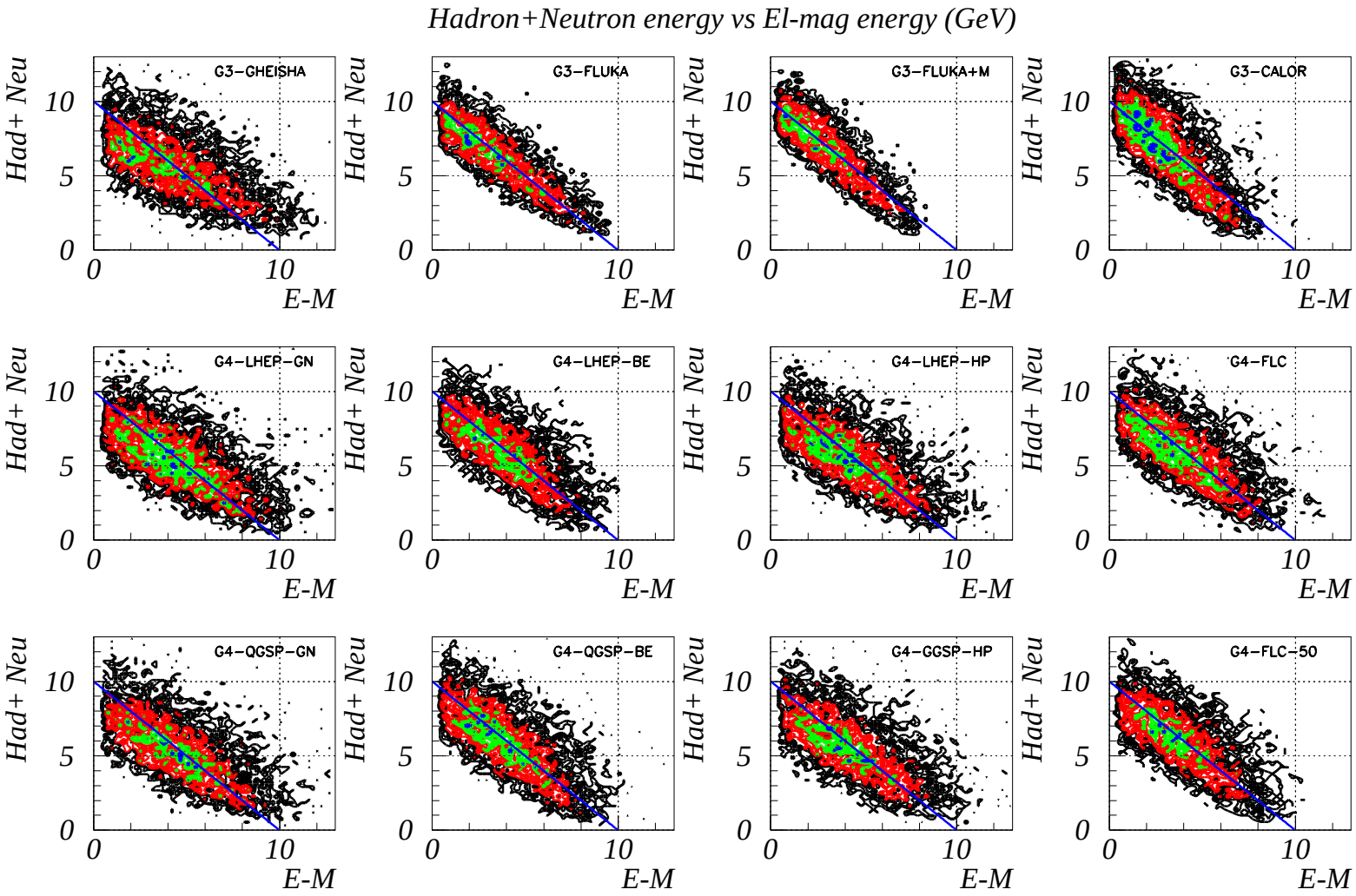
Each event after reconstruction consists of eight digits –

components of energy containment, energy and number of hits for particular type of energy deposition,

they are: N_{EM}, E_{EM}; N_{TRK}, E_{TRK}; N_{HAD}, E_{HAD}; N_{NEUT}, E_{NEUT}.

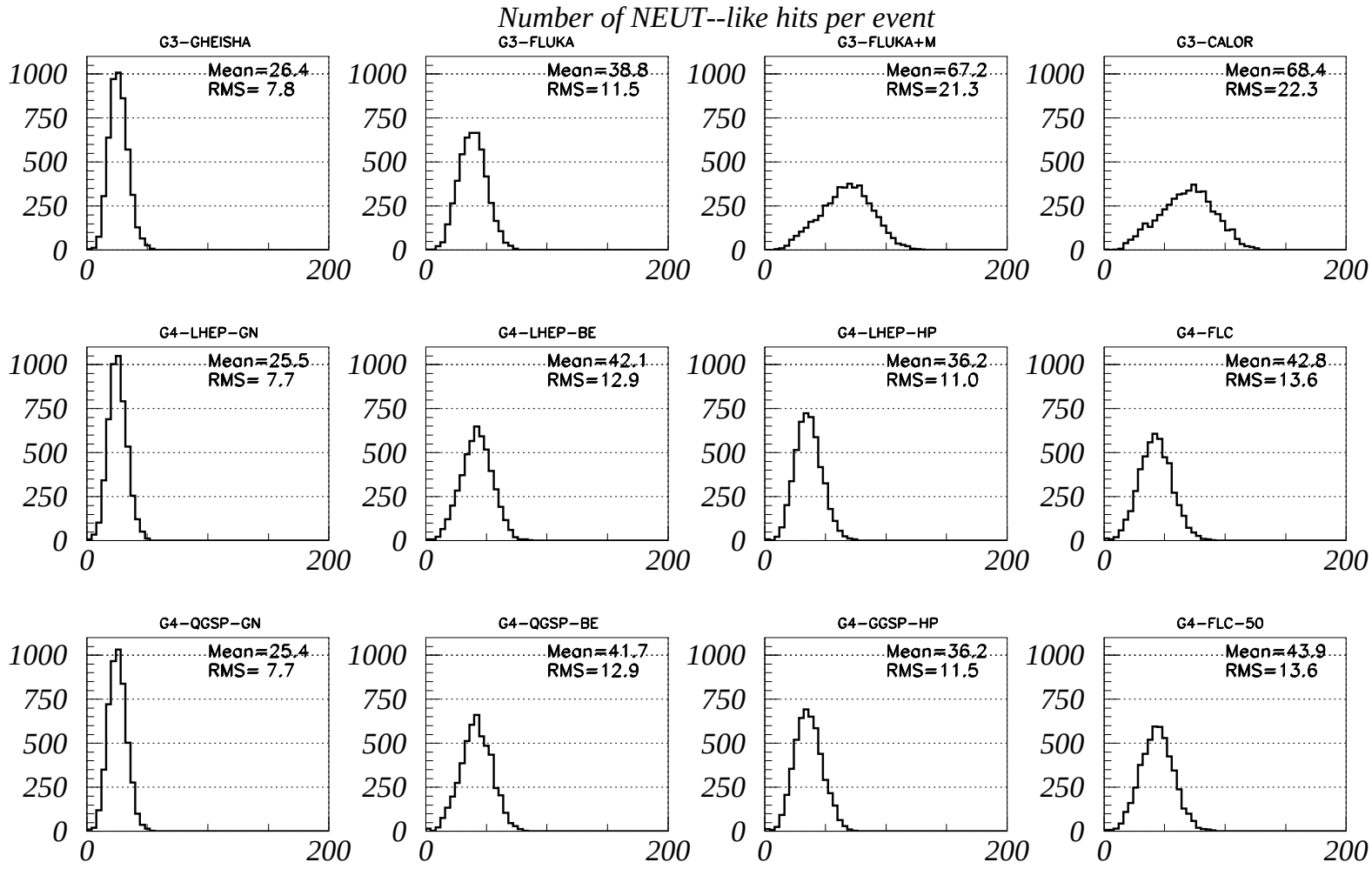
At this way the energy of each event could be presented as sum of four component instead of sum of all hit amplitudes.

Track+Hadron+Neutron Energy VS E-M Energy



The correlation between different components of shower is better in FLUKA than in all other models, it leads to better predicted energy resolution.

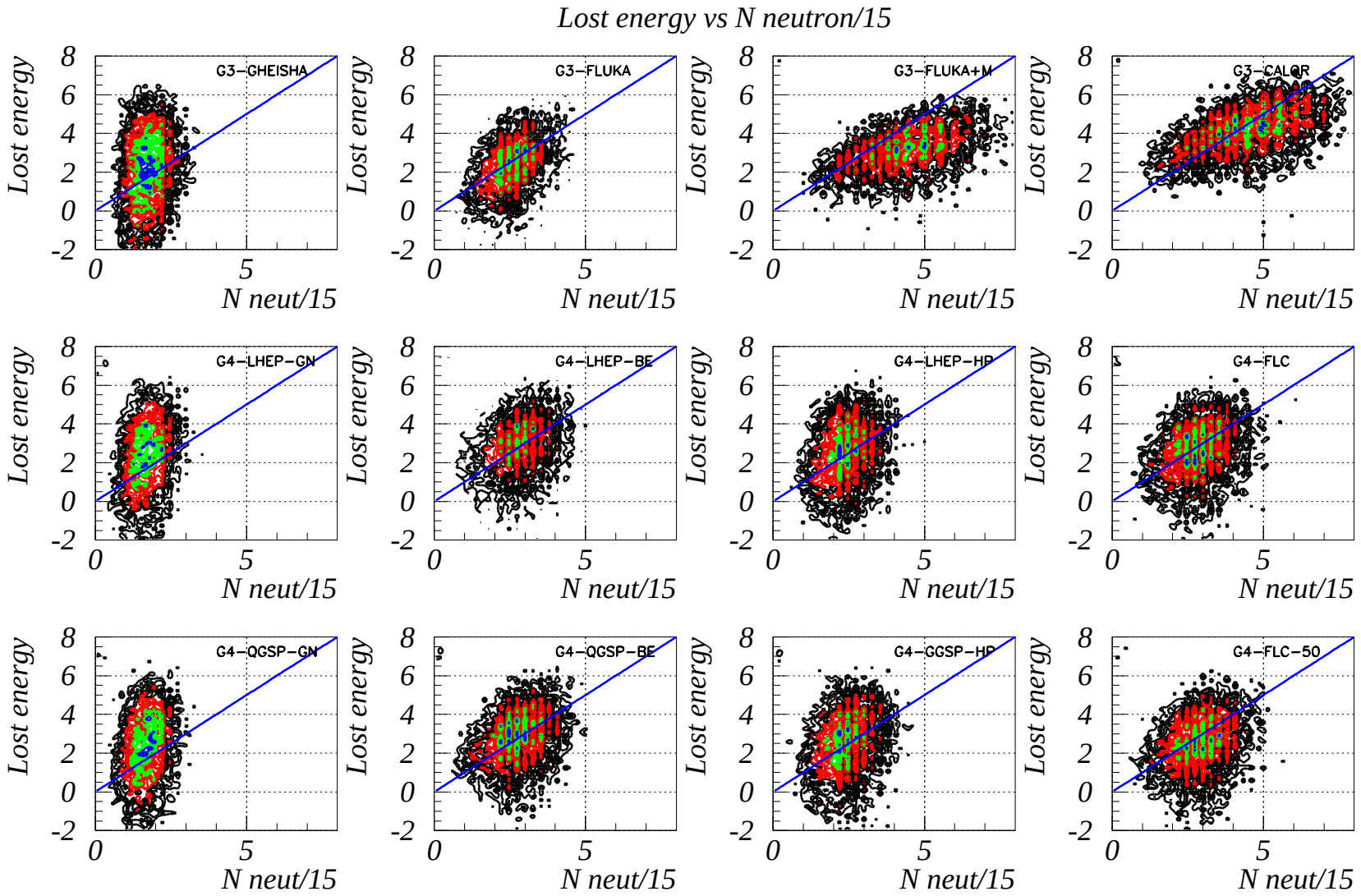
Number of reconstructed neutron–like hits, π+ 10 GeV



It seems to me than the low energy neutron transport does not work in HP models of GEANT4

Lost Energy VS Number of Neutron Hits

Let us defi ne a binding energy as $E_{beam} - (E_{EM} + E_{HAD} + E_{TRK})$ – just lost energy excluding neutron signals.



Observation summary

- 1. A big difference in the raw amplitude normalized spectrum shapes was observed for different programs;
- 2. A MIP peak position kept in range of 840–828 keV for all programs;
- 3. Estimated width of MIP peak has spread from 66 to 109 keV, with visible dependence on the range cut.
- 4. Transport of muons gives very close results ($\pm$1.5%) in the reconstructed energy.
- 5. Pion energy reconstructed with the same sampling coefficient needs a correction coefficient to fit the beam energy and its spread from 1 to 1.6 for different programs;
- 6. Energy correction coefficients for 2 GeV electron show a difference mostly between GEANT3 and GEANT4, 1.27 and 1.34 correspondingly.
- 7. Energy resolution (for simple sum of hit energies) has a big spread for GEANT3 programs and less spread for GEANT4 programs
- 8. The Bertini intarnuclear cascade model used in both G3 and G4 give the smallest spread of the calorimeter energy resolution, less than ten percent in absolute value;
- 9. The tree of four GEANT3 programs give the spread from 1.07 to 1.25 GeV in energy resolution;
- 10. The longitudinal energy distributions show similar behaviour but differ in the estimation of peak value itself and differ at the tail.

Observation summary

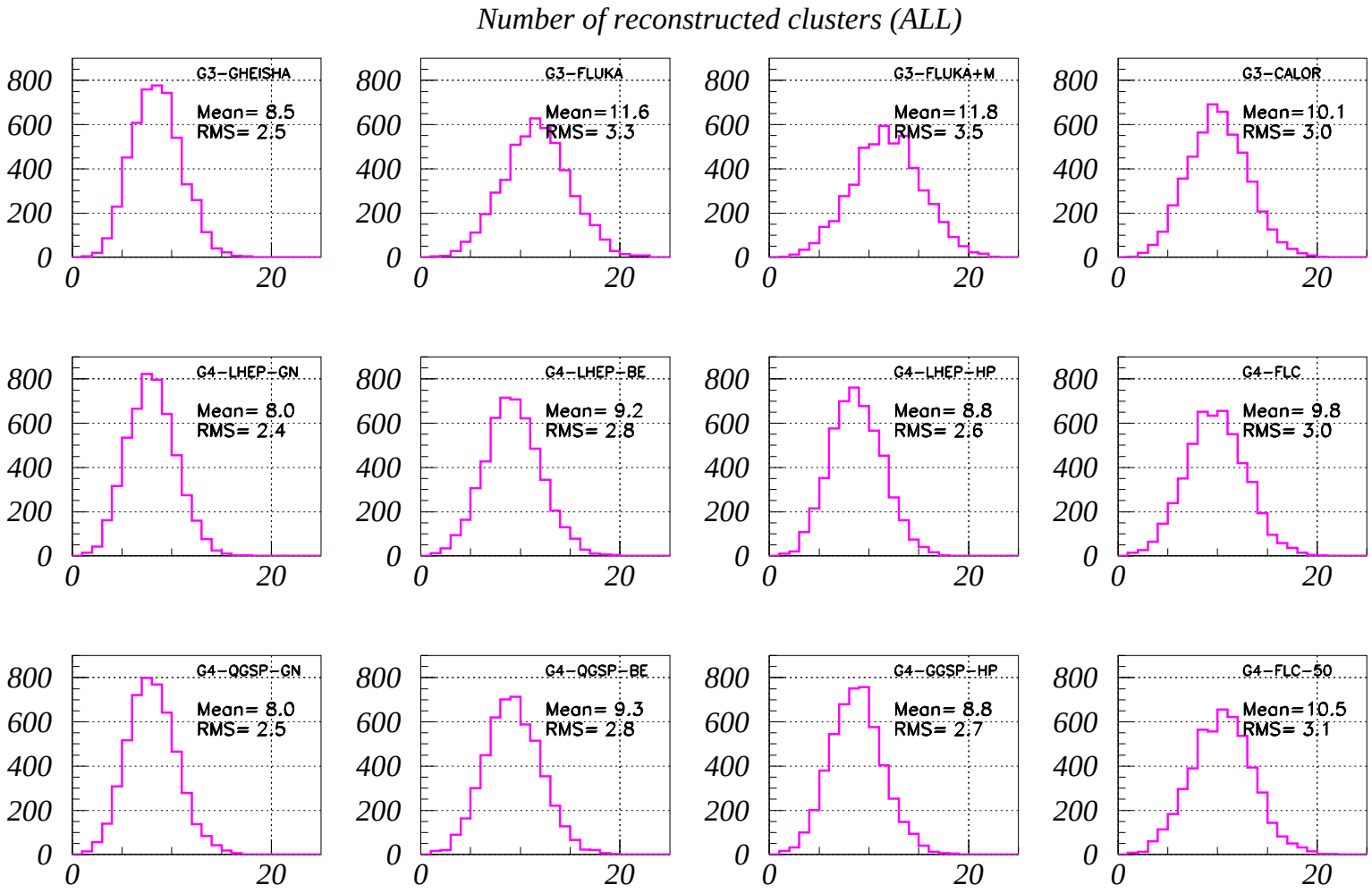
- 11. Average number of hits in event shows spread from 115 to 195.
- 12. The rather big difference in shapes of energy to number of hit correlation was observed.
- 13. The distribution of average hit energy in event shows a big difference in its shape as well as any other parameters.
- 14. The average hit energy value is in agreement for all GHEISHA models independently on the programs (G3 or G4); as Bertini model in any GEANT4 models.
- 15. FLUKA and GCALOR show the smallest values for average hit energy.
- 16. The correlation between reconstructed electromagnetic component and hadronic component of pion shower is most strong for the FLUKA program; and this is the reason for the better predicted calorimeter energy resolution.
- 17. The distribution of number of hits in event reconstructed as neutron–like has a big spread as in its shape as in its number, even for models with involving of the low energy neutron transport codes as in GEANT3 as in GEANT4.
- 18. The biggest difference in shape shows the correlation between the lost energy in event and the number of neutron–like hits.

Conclusion

The prediction power of the different hadronic models in GEANT3 and GEANT4 is in between factor 2 and 1.2; and it depends on the quantity one would like to extract from the simulation.

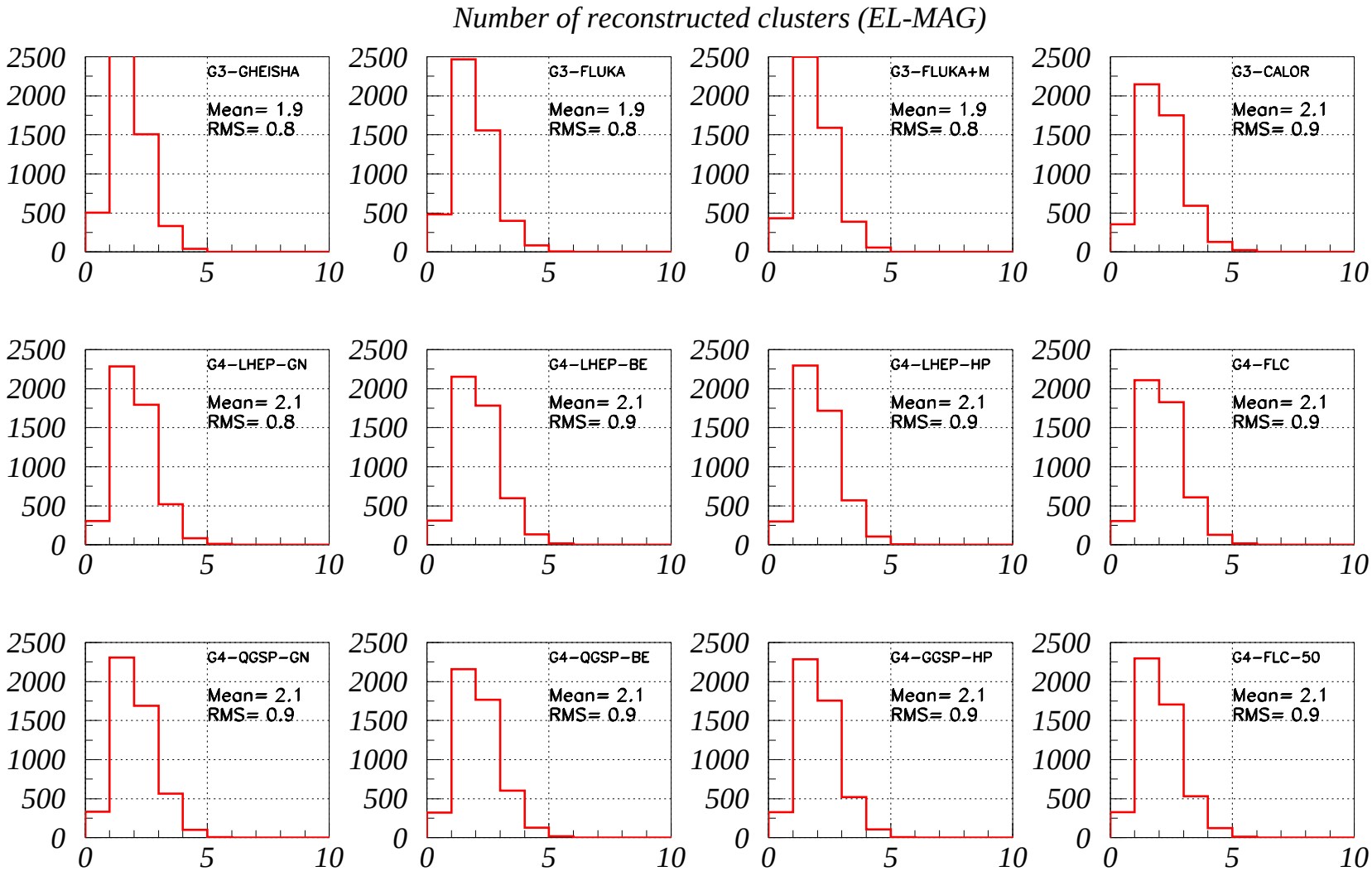
Support slides

Number of Reconstructed Clusters, π+ 10 GeV



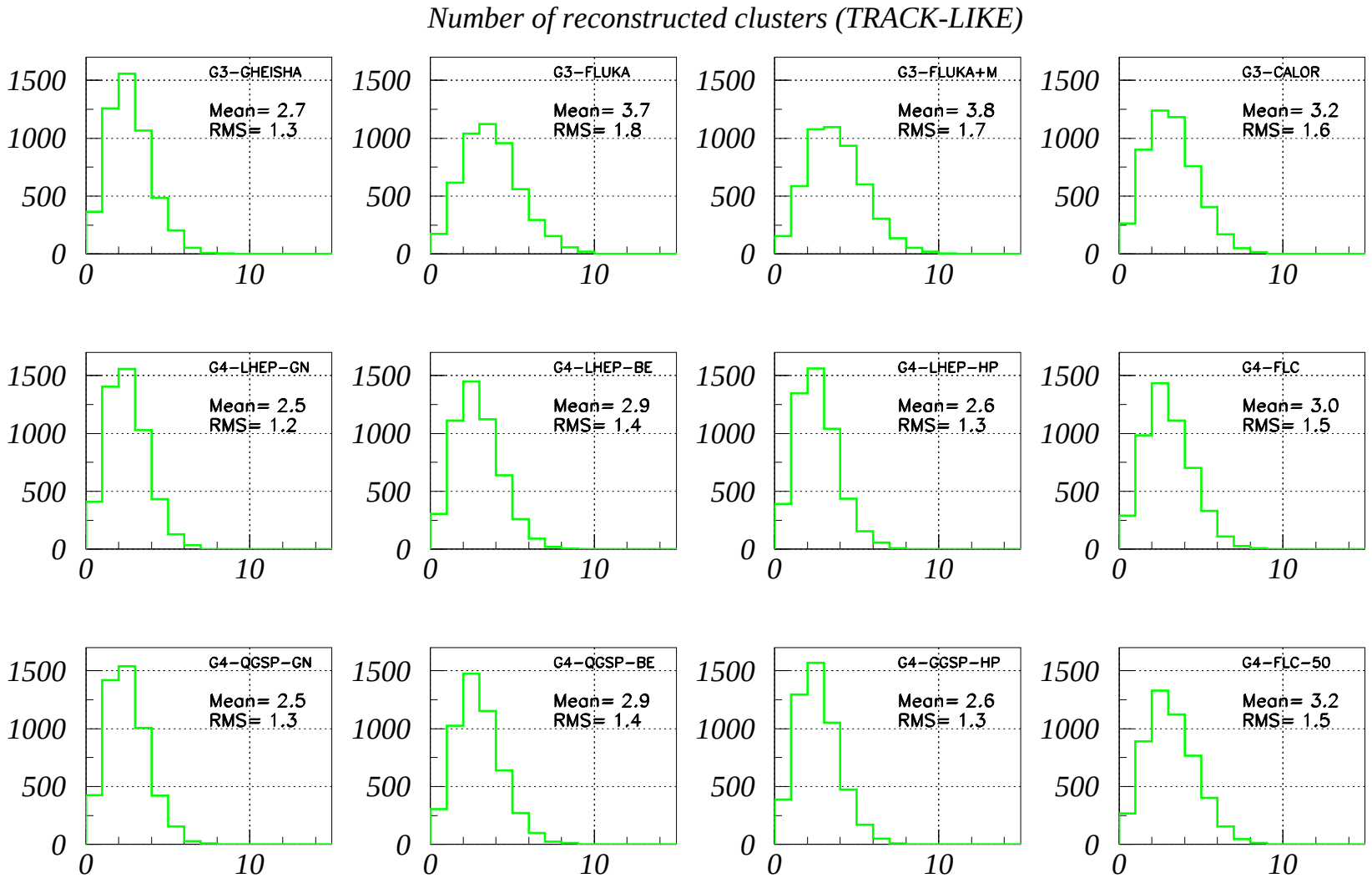
The spread is not big from 8.0 to 11.6, and it is understandable: it is mostly due to low energy neutron transport that added into FLUKA and GCALOR.

Number of Reconstructed E-M Clusters, π+ 10 GeV



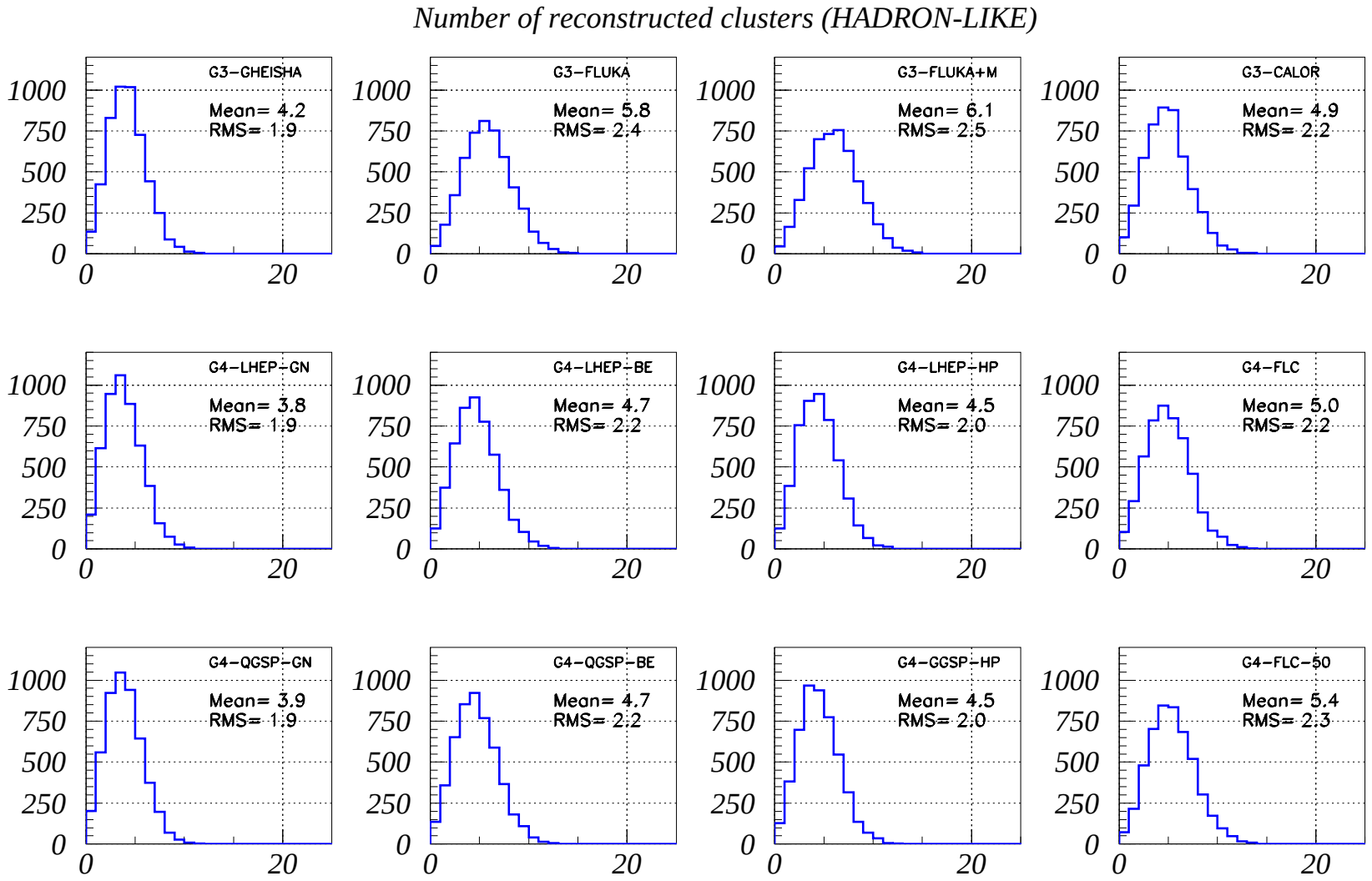
Pretty the same – from 1.9 to 2.1

Number of Reconstructed TRK Clusters, π+ 10 GeV



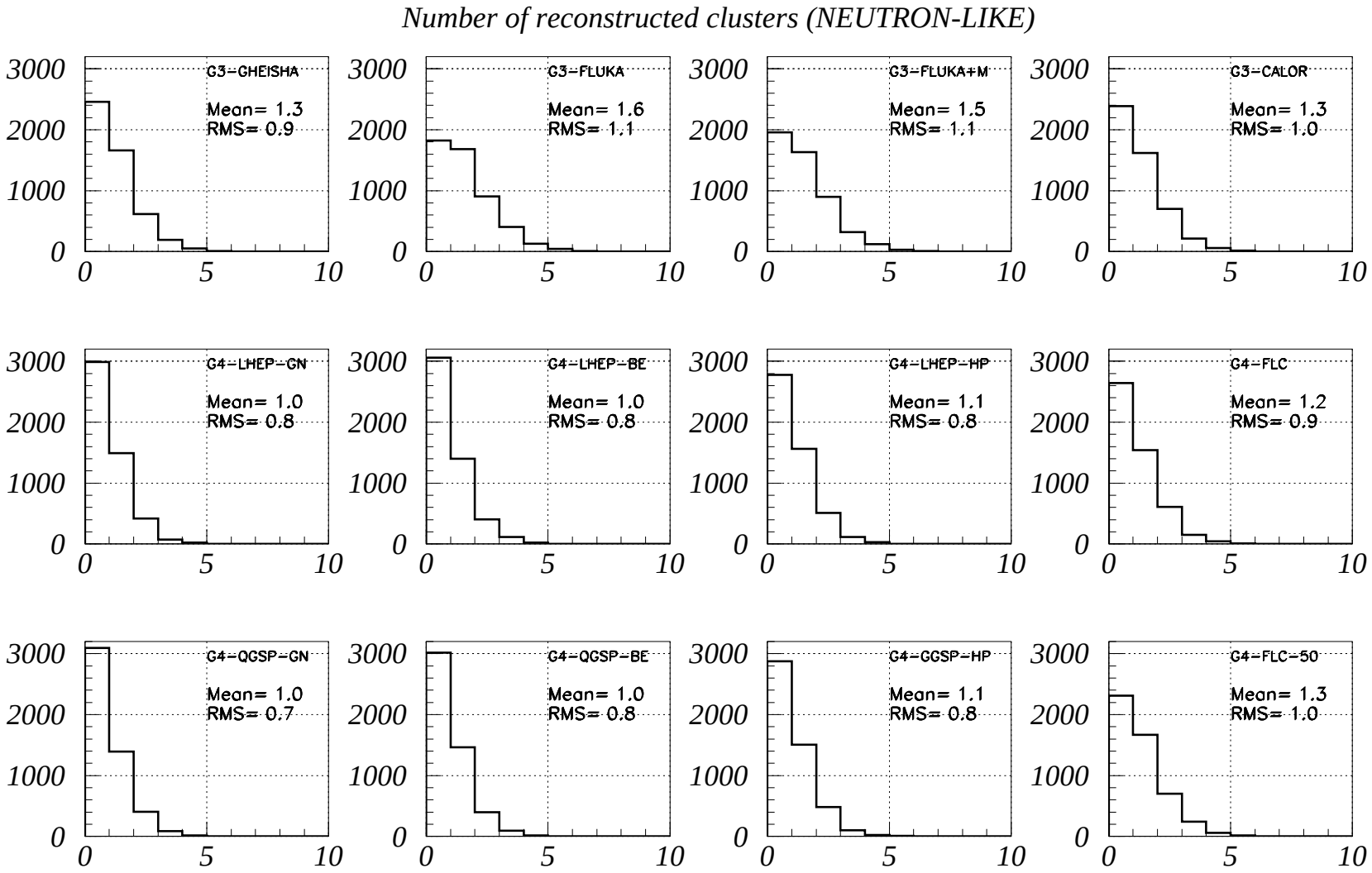
Bigger spread: from 2.5 to 3.8

Number of Reconstructed HADR Clusters, π+ 10 GeV



Big spread: from 3.8 to 6.1

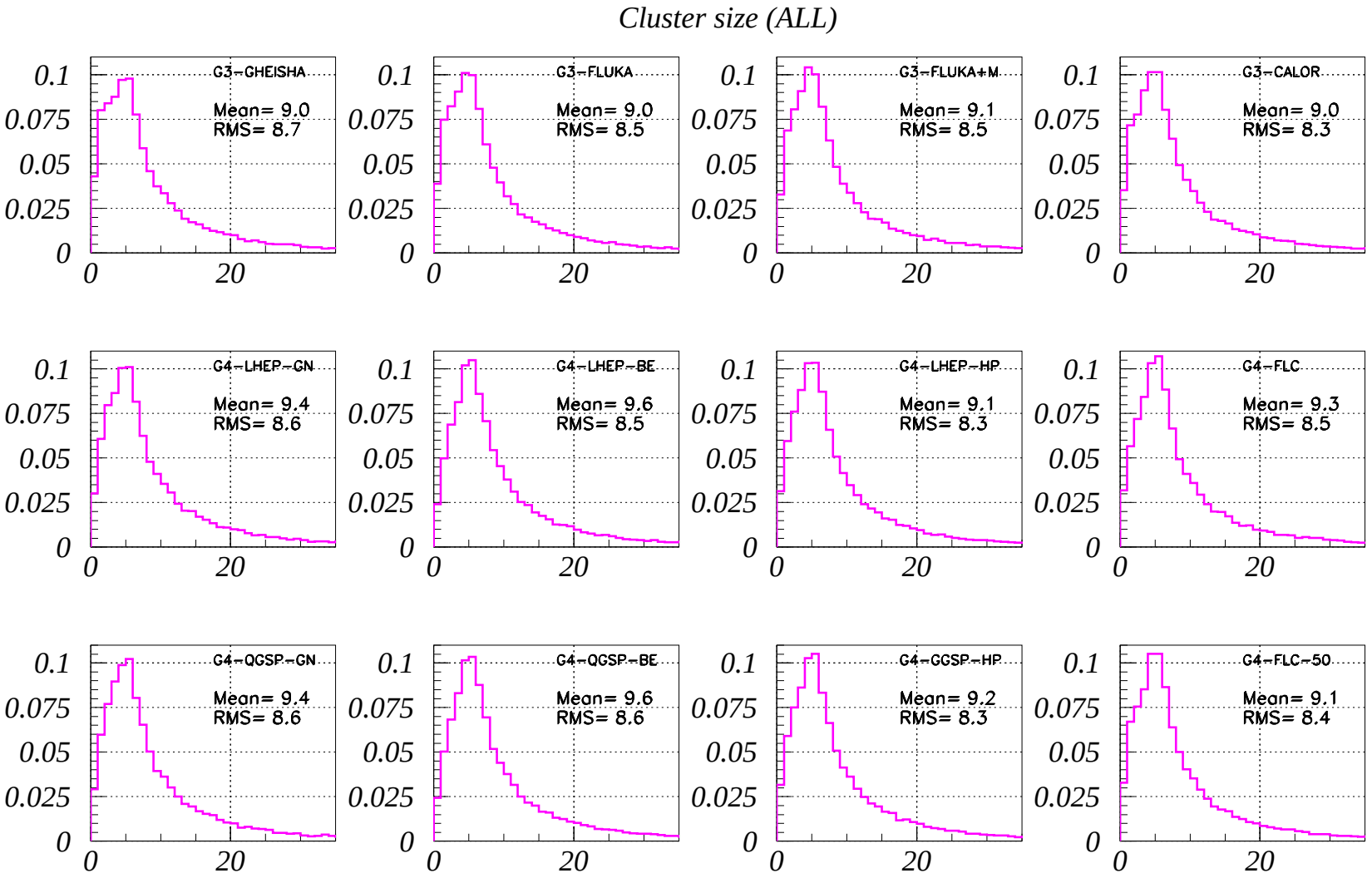
Number of Reconstructed NEUTR Clusters, π+ 10 GeV



spread: from 1.0 to 1.6

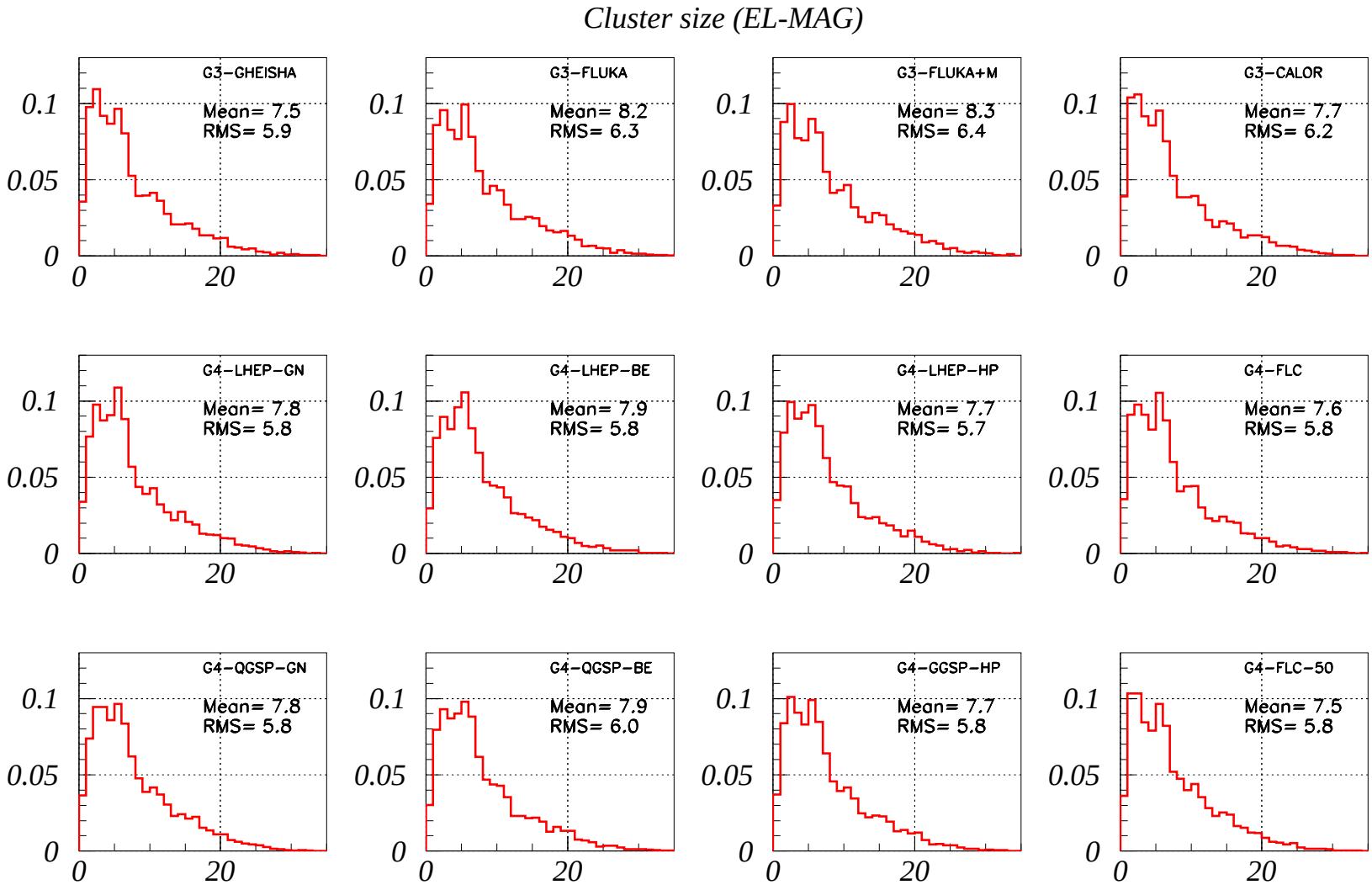
Big

Cluster Size, π+ 10 GeV



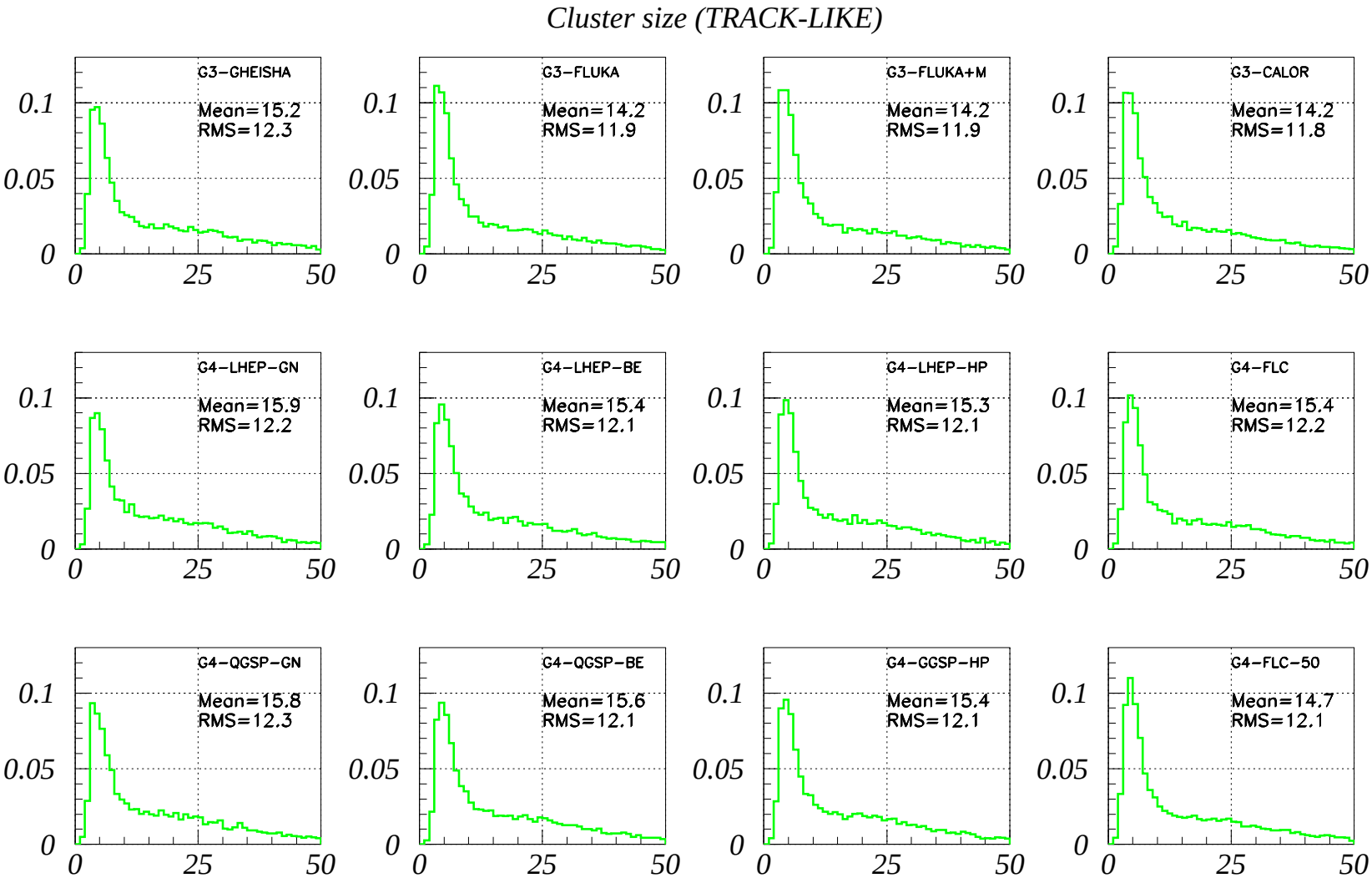
Pretty the same – from 8.6 to 9.1

E-M Cluster Size, π+ 10 GeV



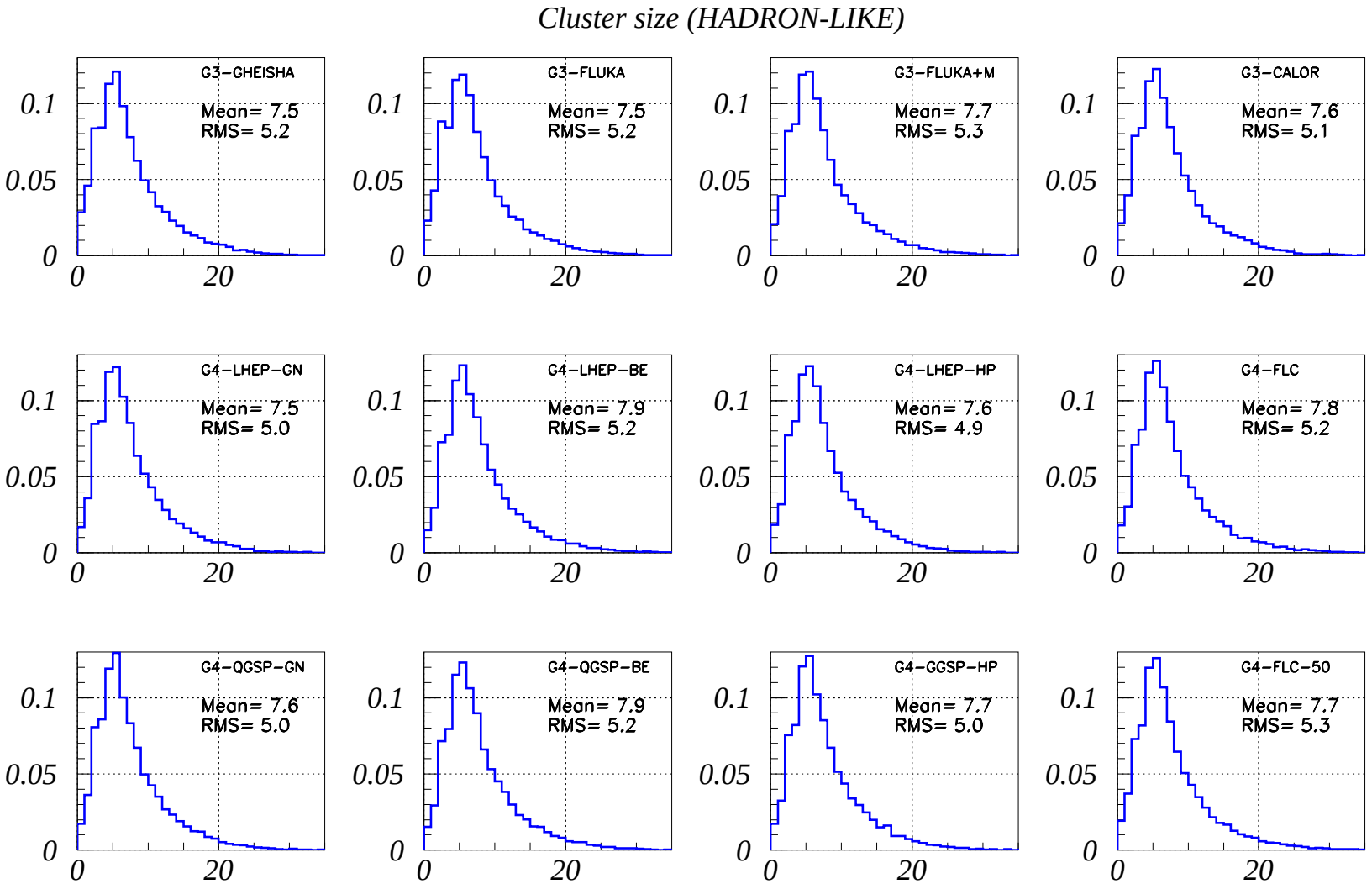
Small spread – from 7.5 to 8.3

TRK Cluster Size, π+ 10 GeV



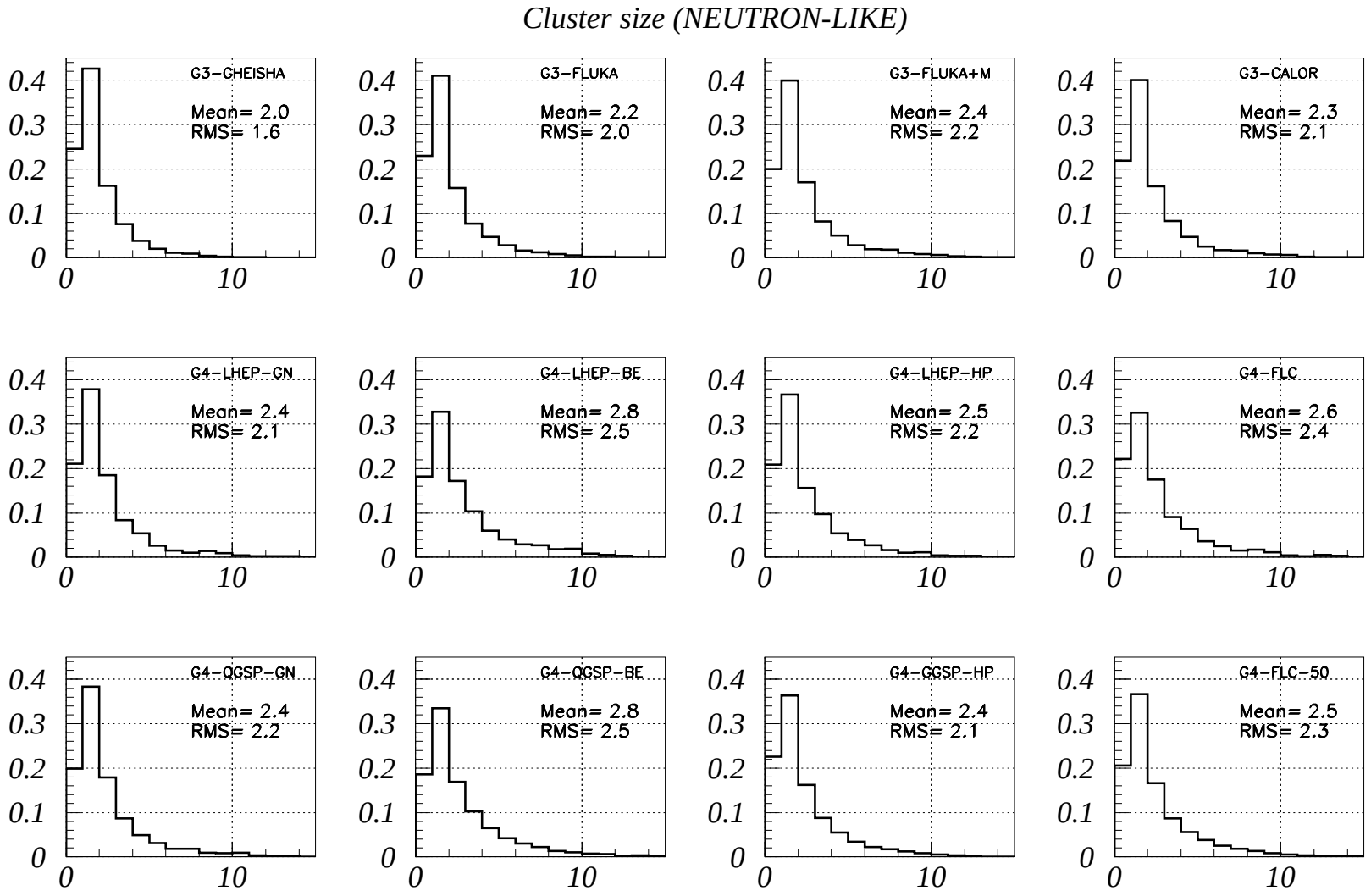
Pretty the same – from 14.2 to 15.8

HADR Cluster Size, π+ 10 GeV



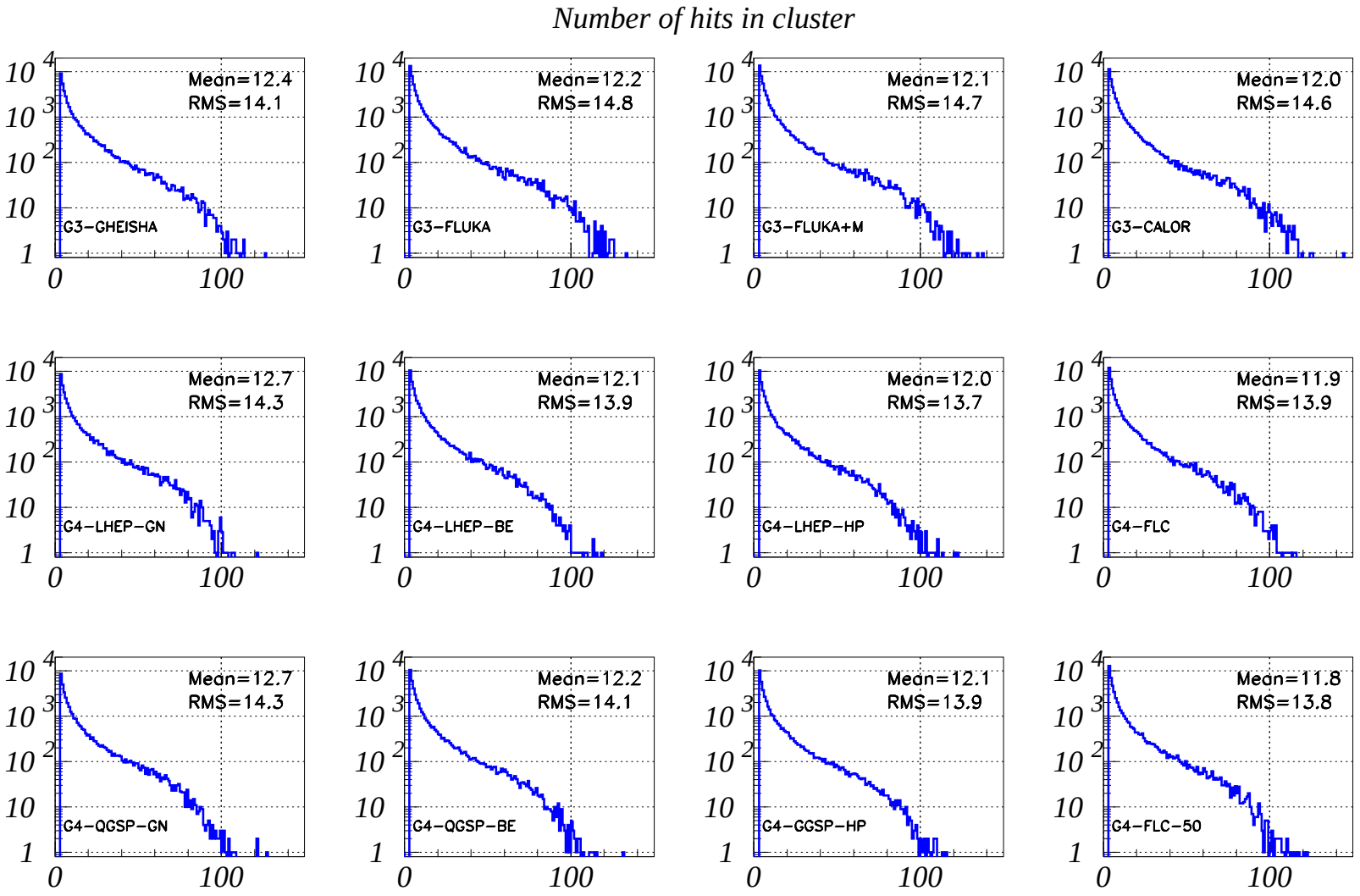
Pretty the same – from 7.5 to 7.9

NEUT Cluster Size, π+ 10 GeV

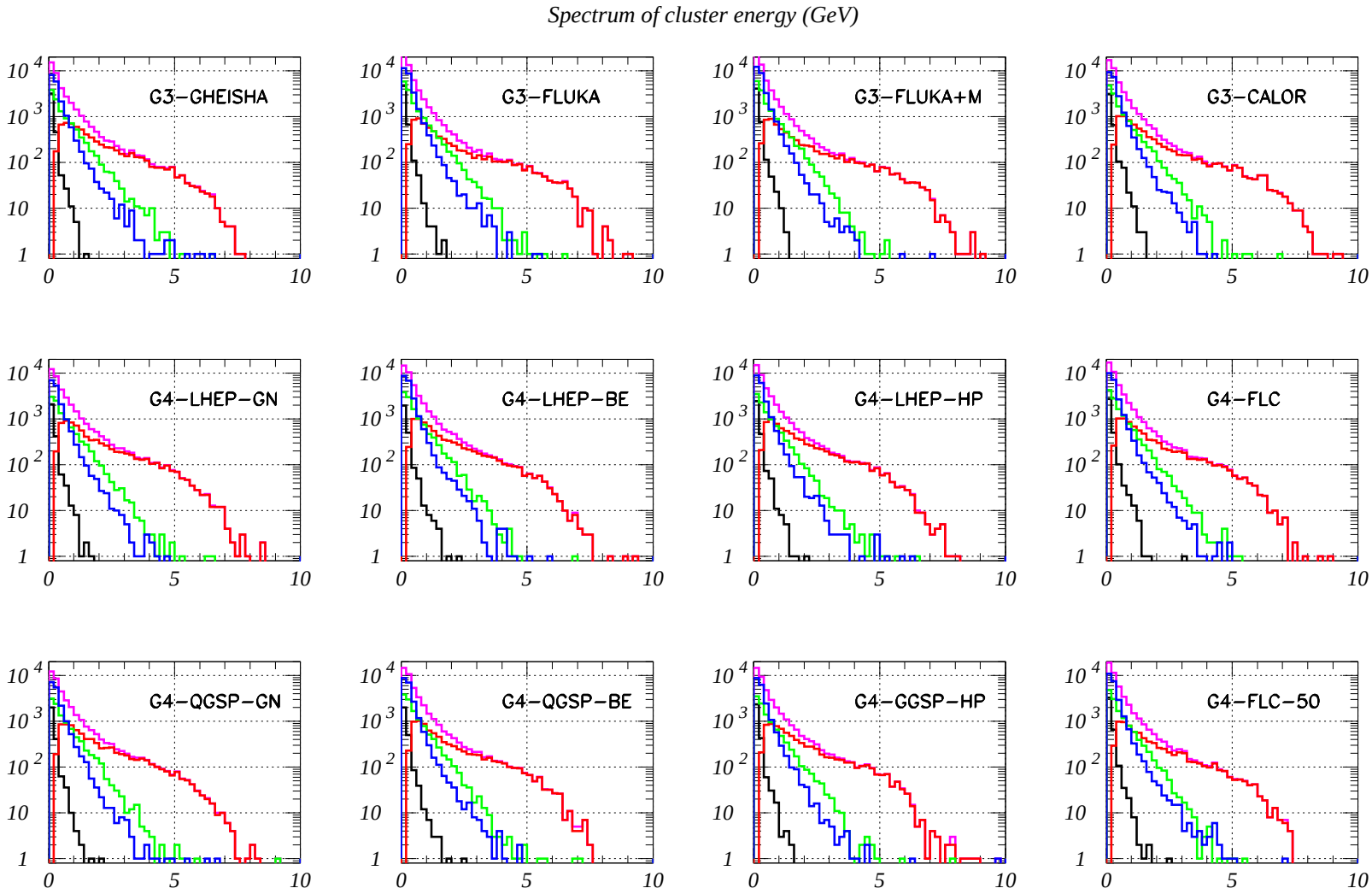


Small spread – from 2.0 to 2.8

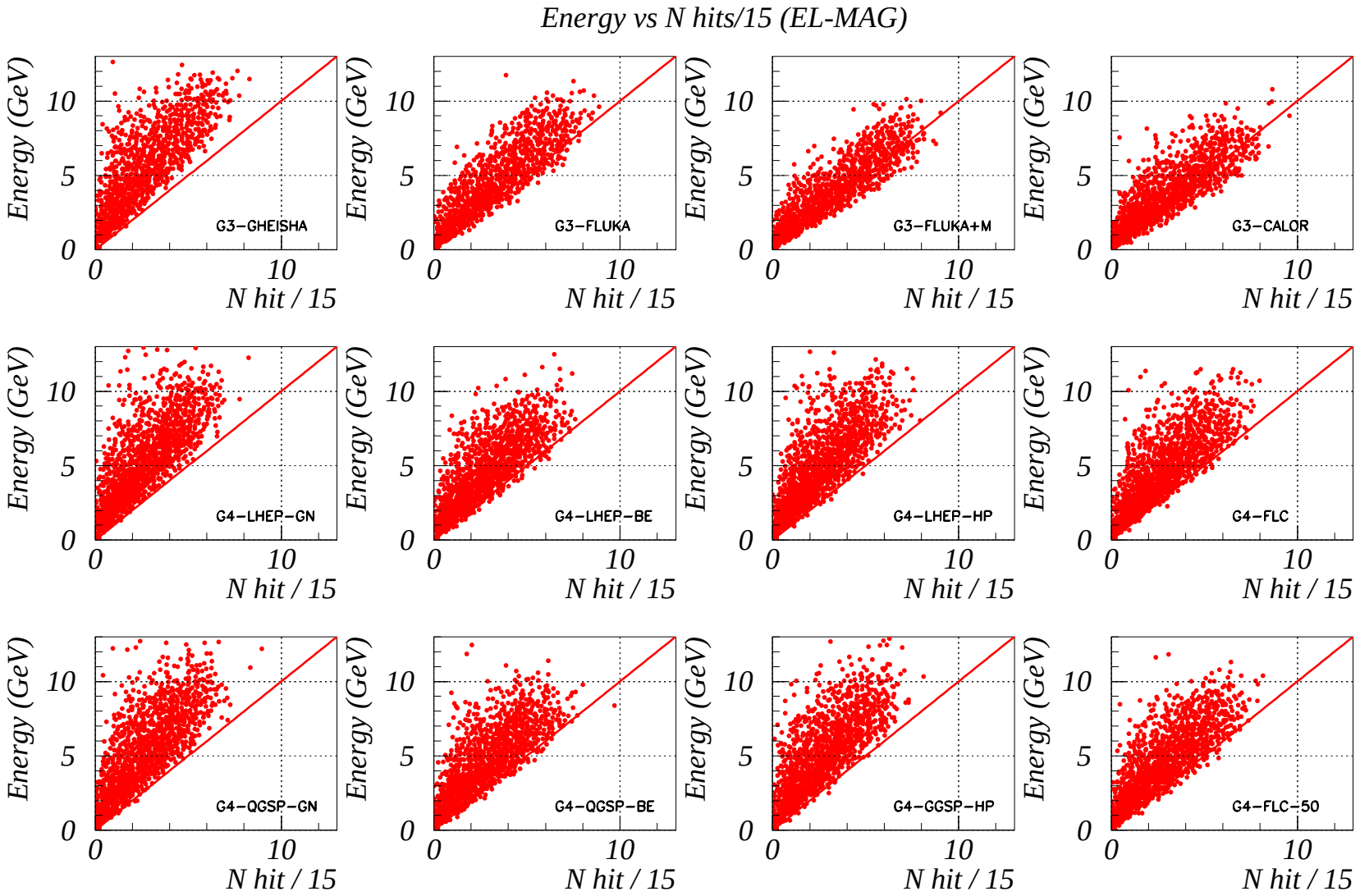
Number of Hits in Cluster, π+ 10 GeV



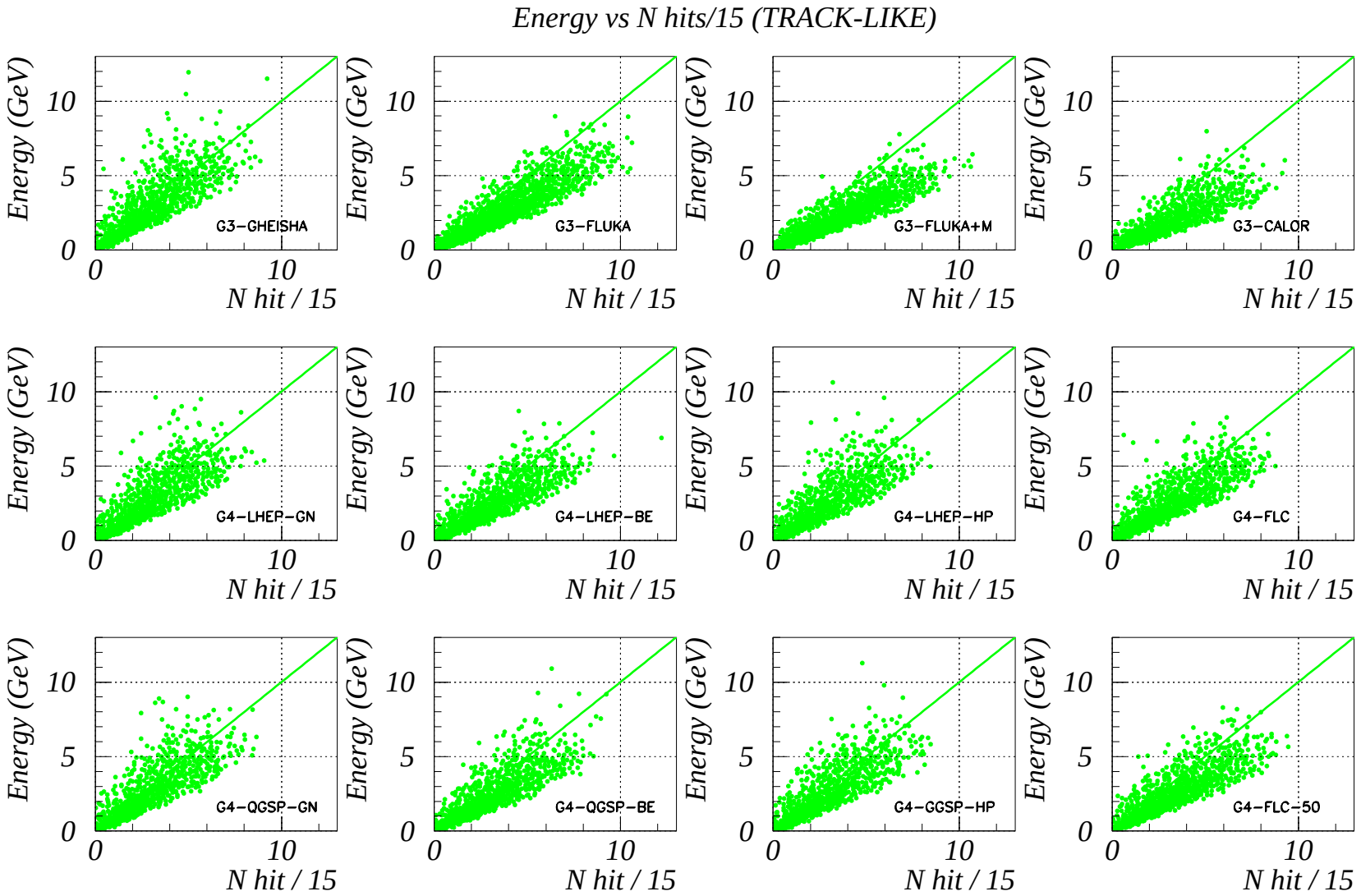
Spectrum of Cluster Energy, π+ 10 GeV



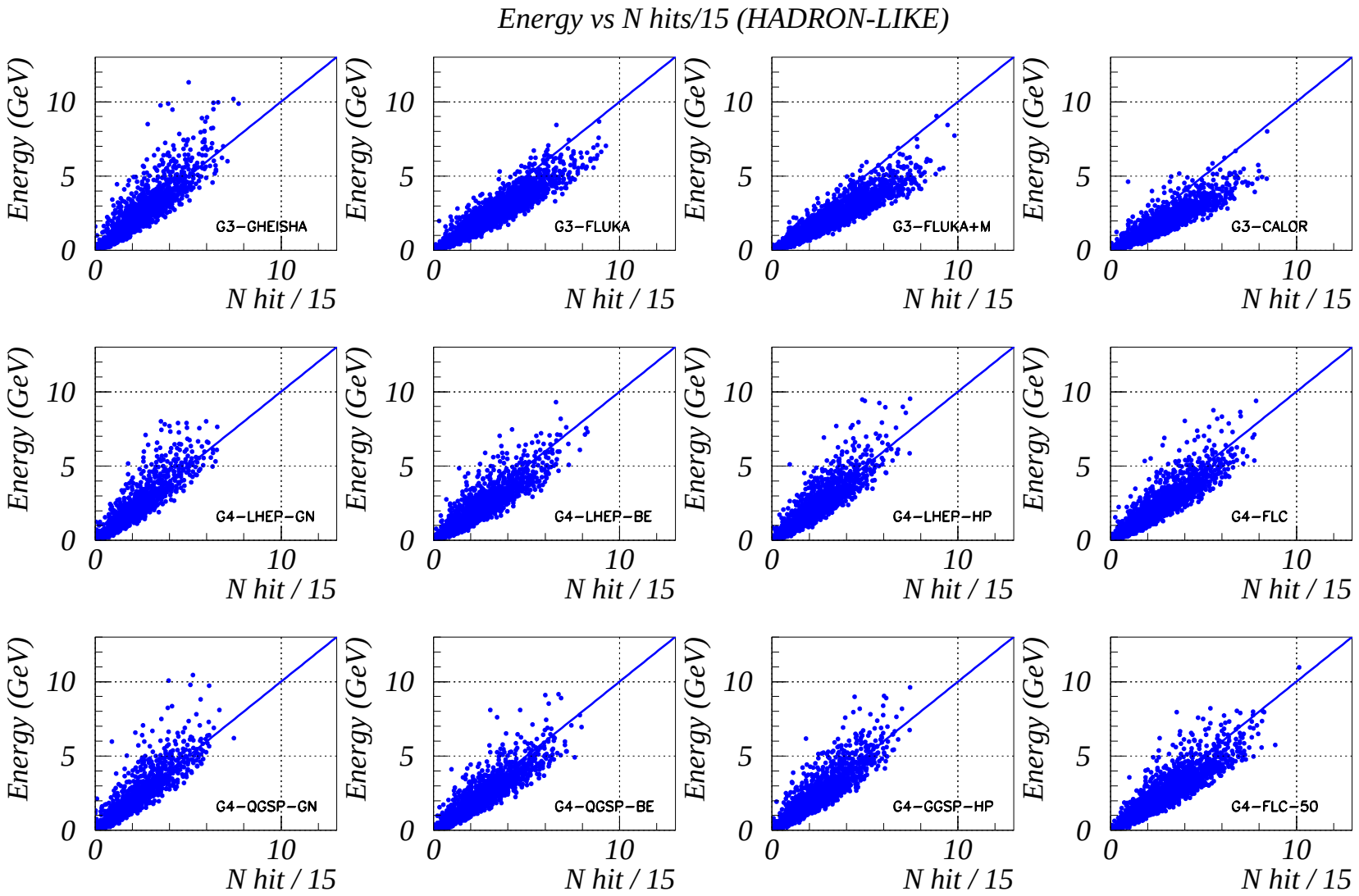
Sum of Hit Energy VS Number of Hits, E-M, π+ 10 GeV



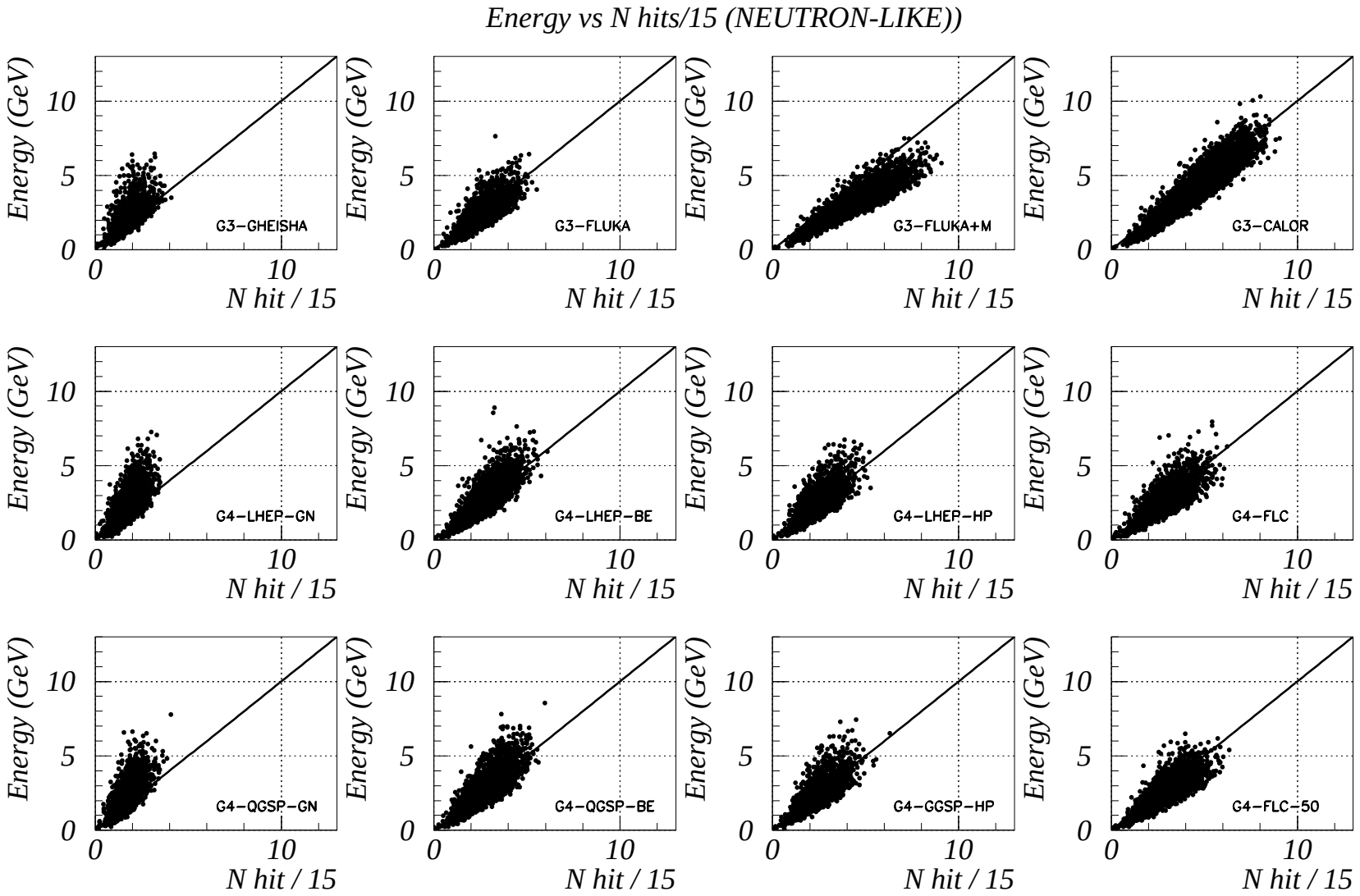
Sum of Hit Energy VS Number of Hits, TRK, π+ 10 GeV



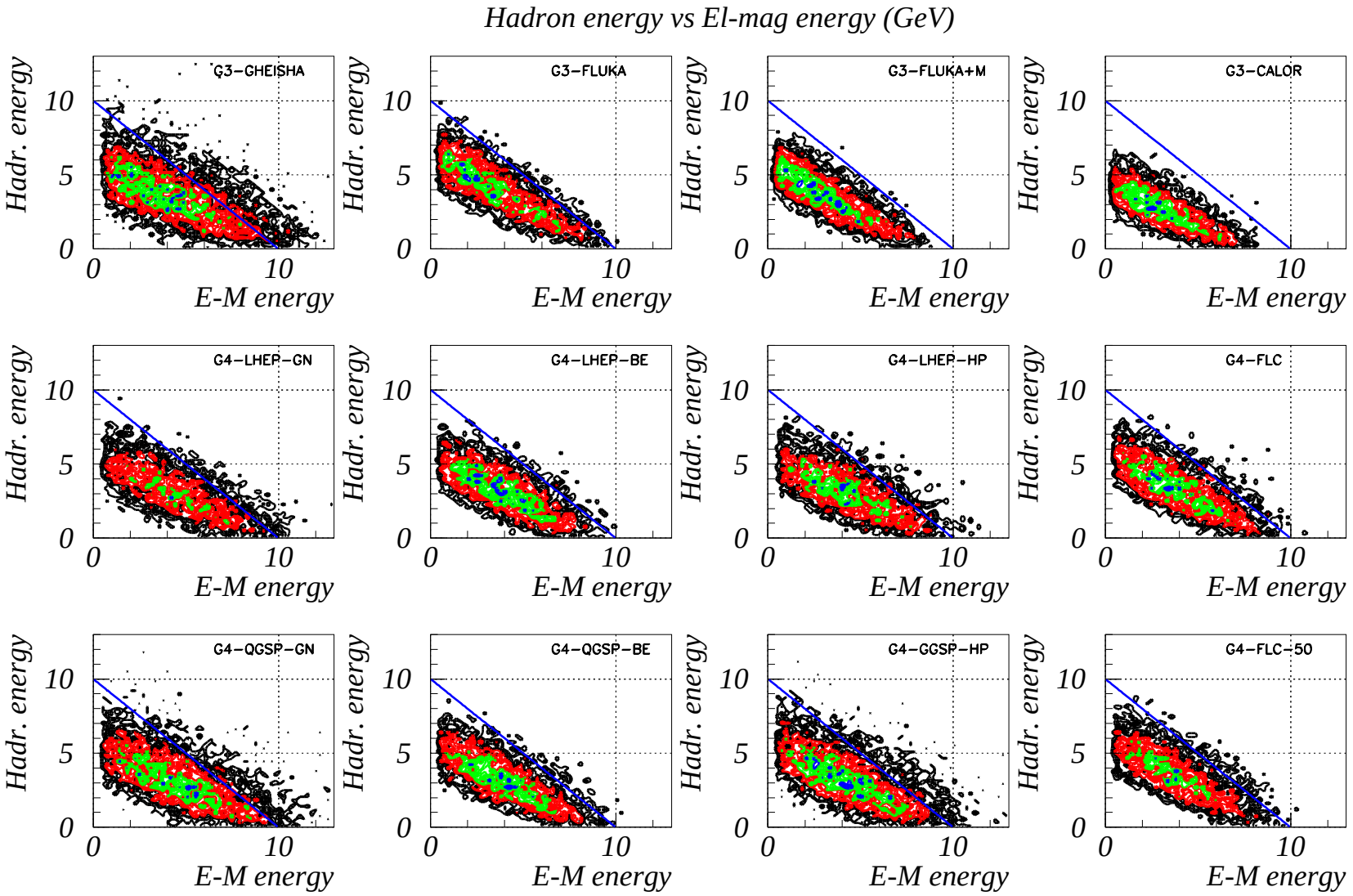
Sum of Hit Energy VS Number of Hits, HADR, π+ 10 GeV



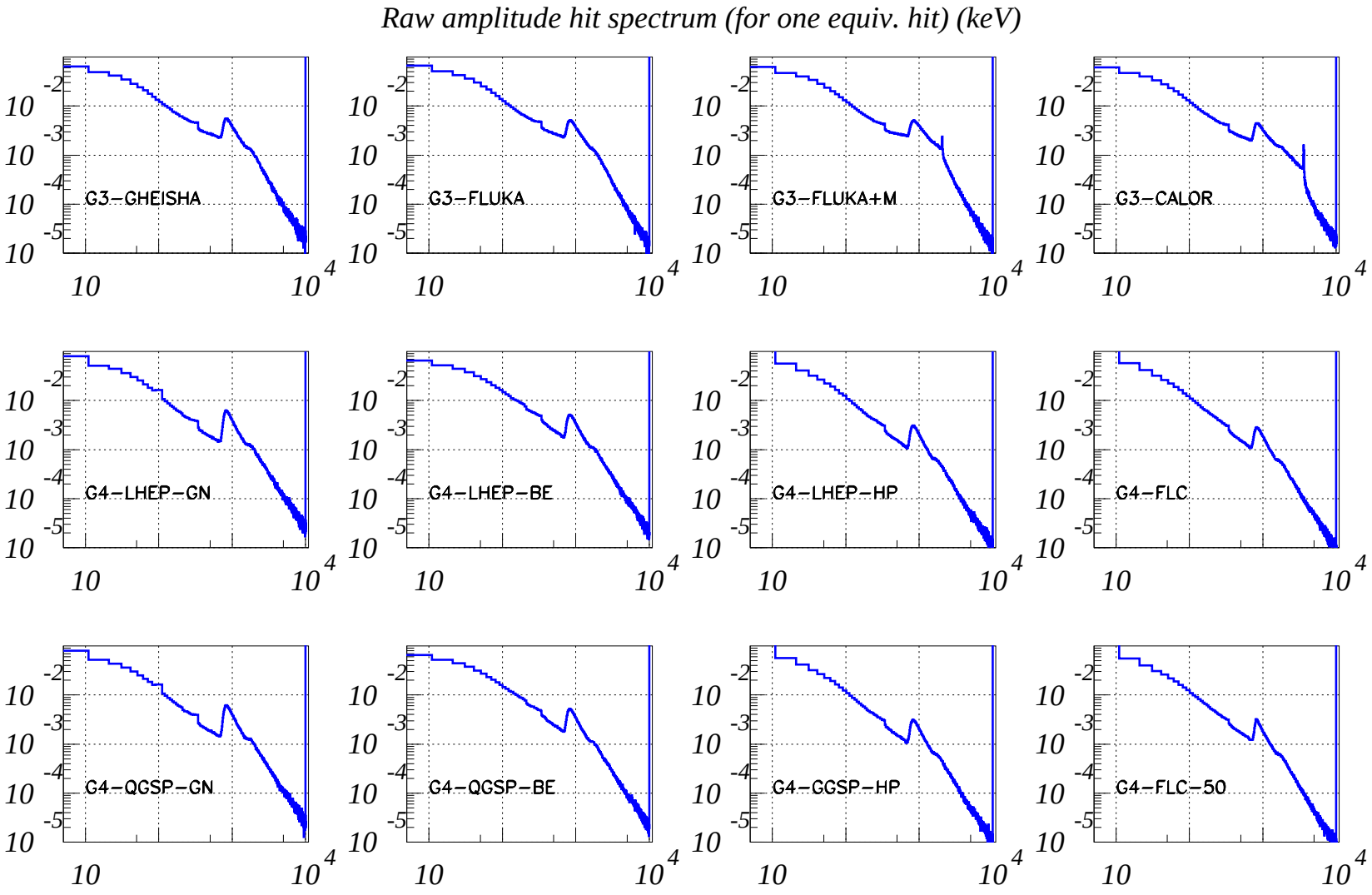
Sum of Hit Energy VS Number of Hits, NEUTR, π+ 10 GeV



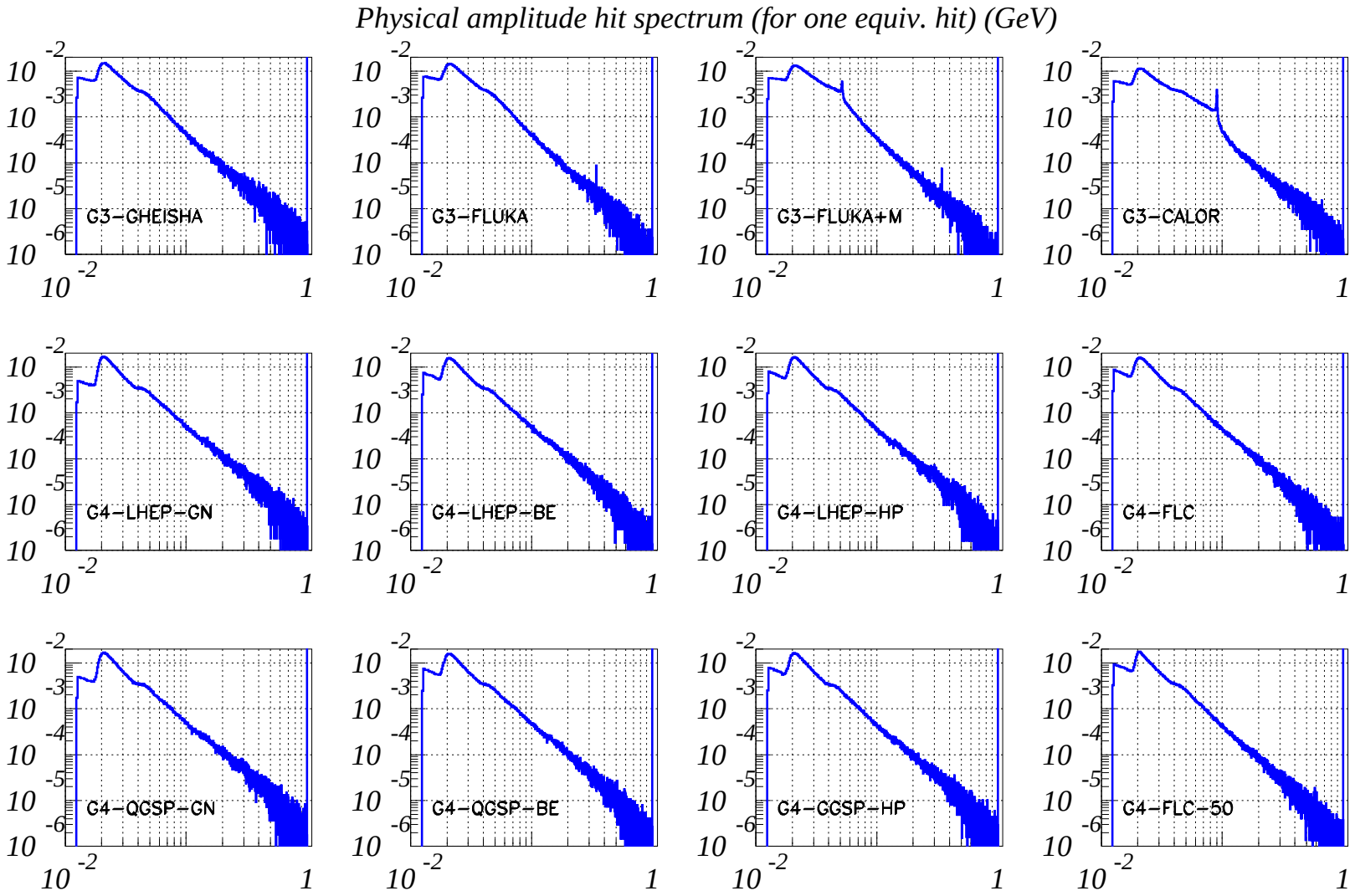
Hadron Energy VS E-M Energy, π+ 10 GeV



Raw amplitude spectrum, π+ 10 GeV

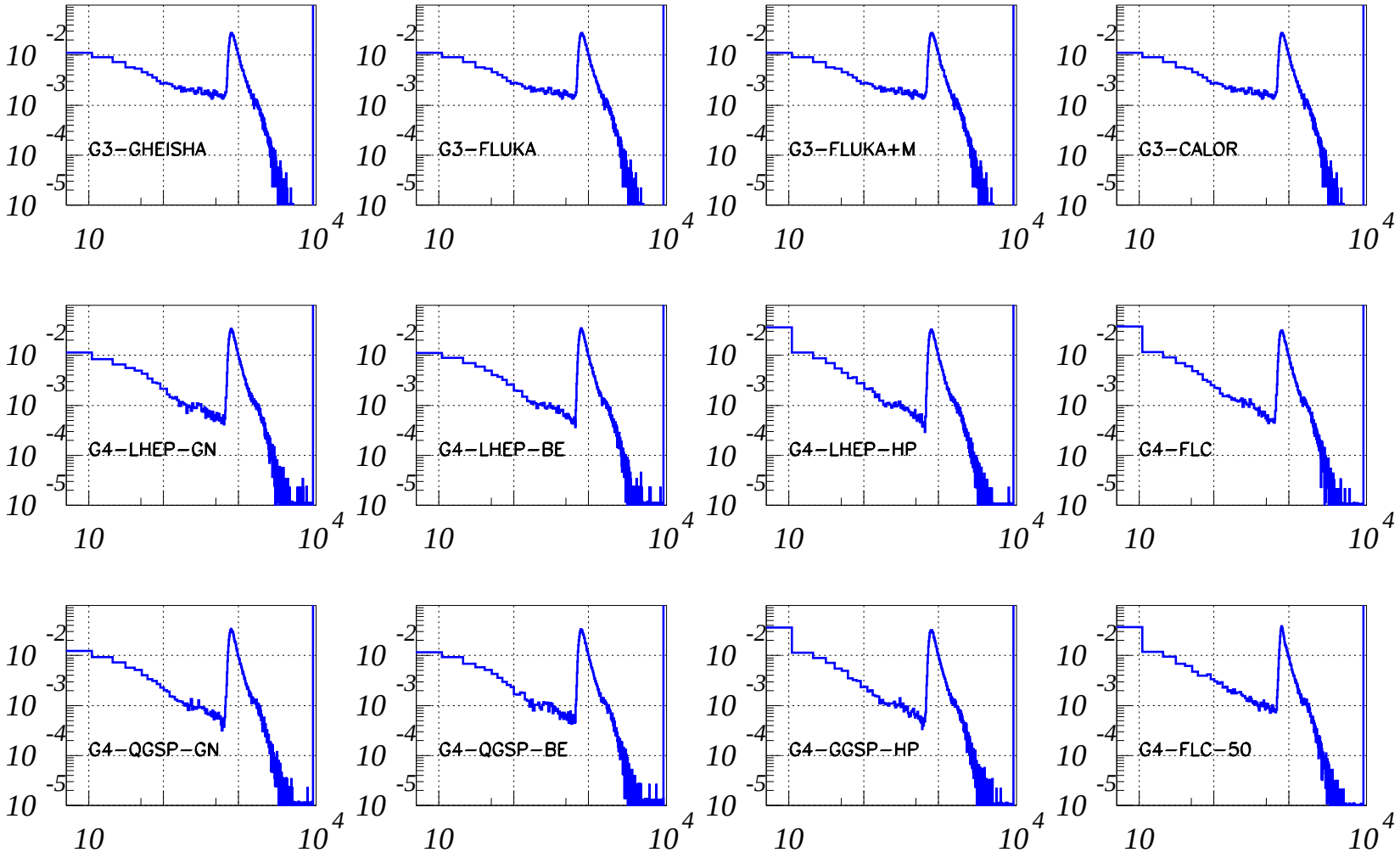


Physical Amplitude Hit Spectrum π 10 GeV



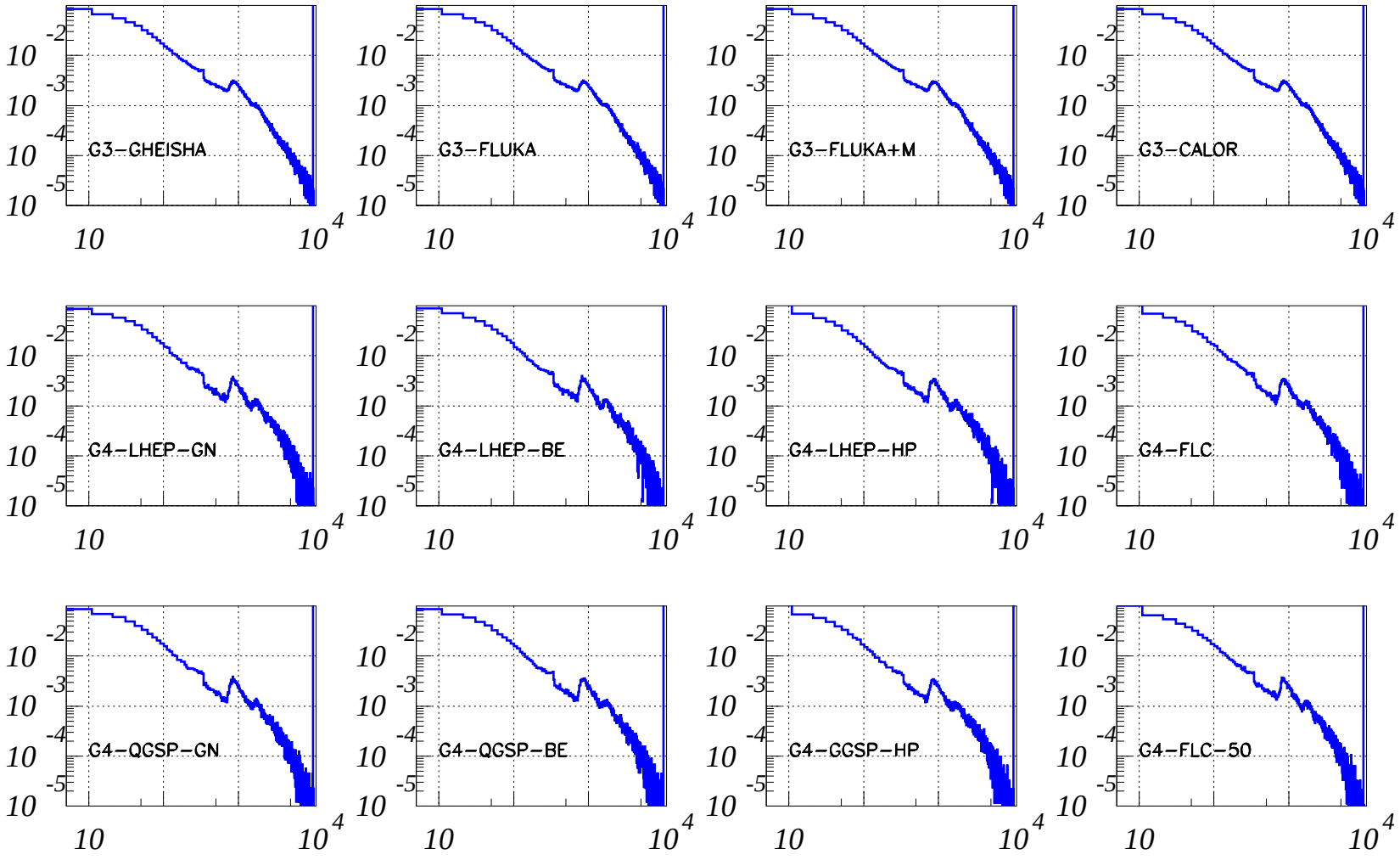
Raw amplitude spectrum μ 2 GeV

Raw amplitude hit spectrum (for one equiv. hit) (keV)

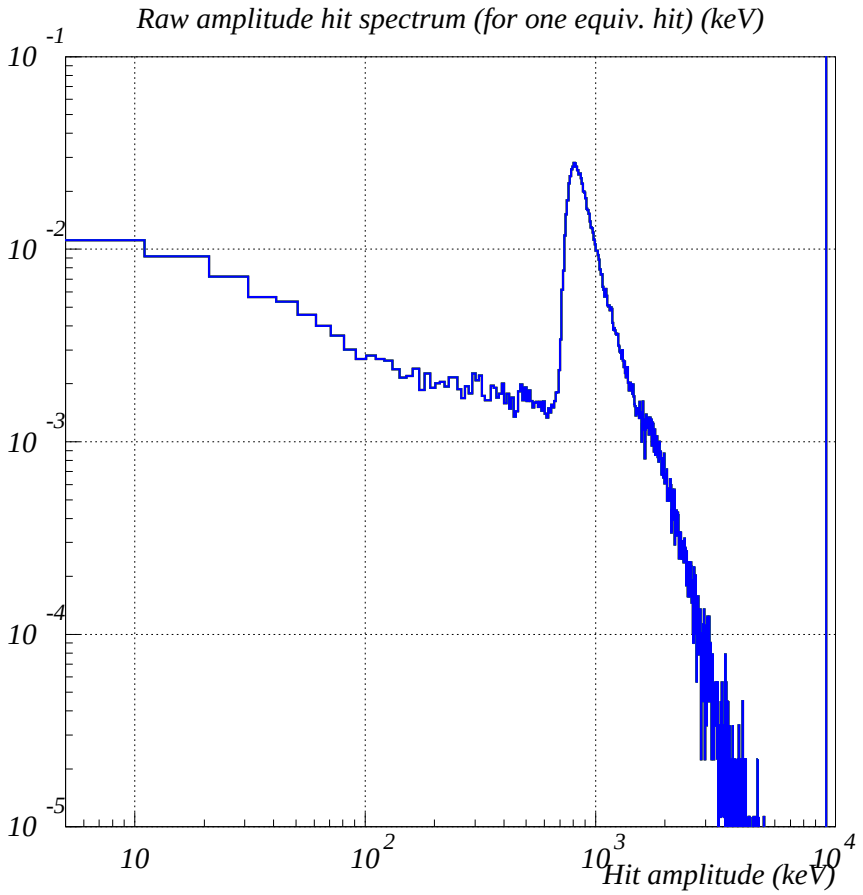


Raw amplitude spectrum e 2 GeV

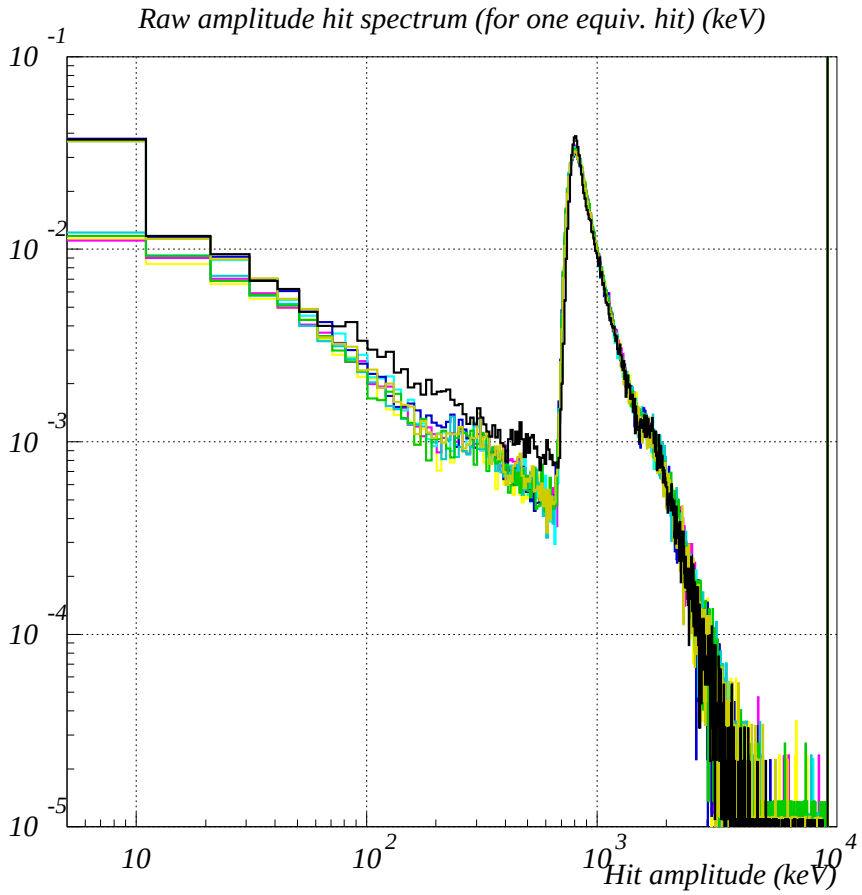
Raw amplitude hit spectrum (for one equiv. hit) (keV)



Raw amplitude spectrum μ 2 GeV

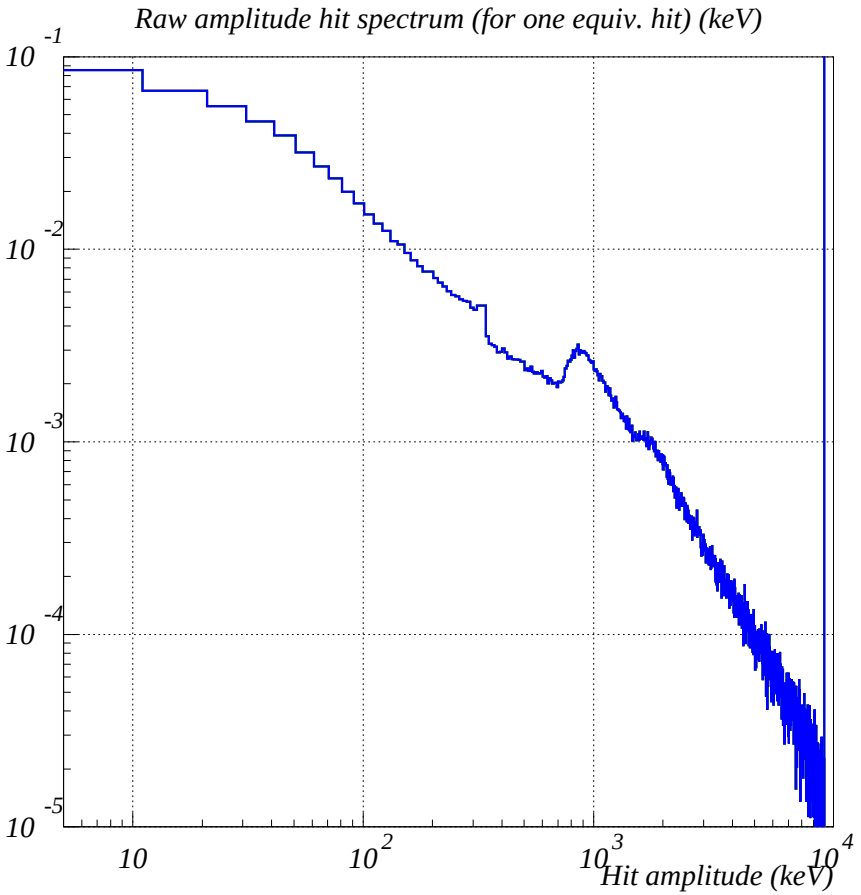


GEANT 3 only

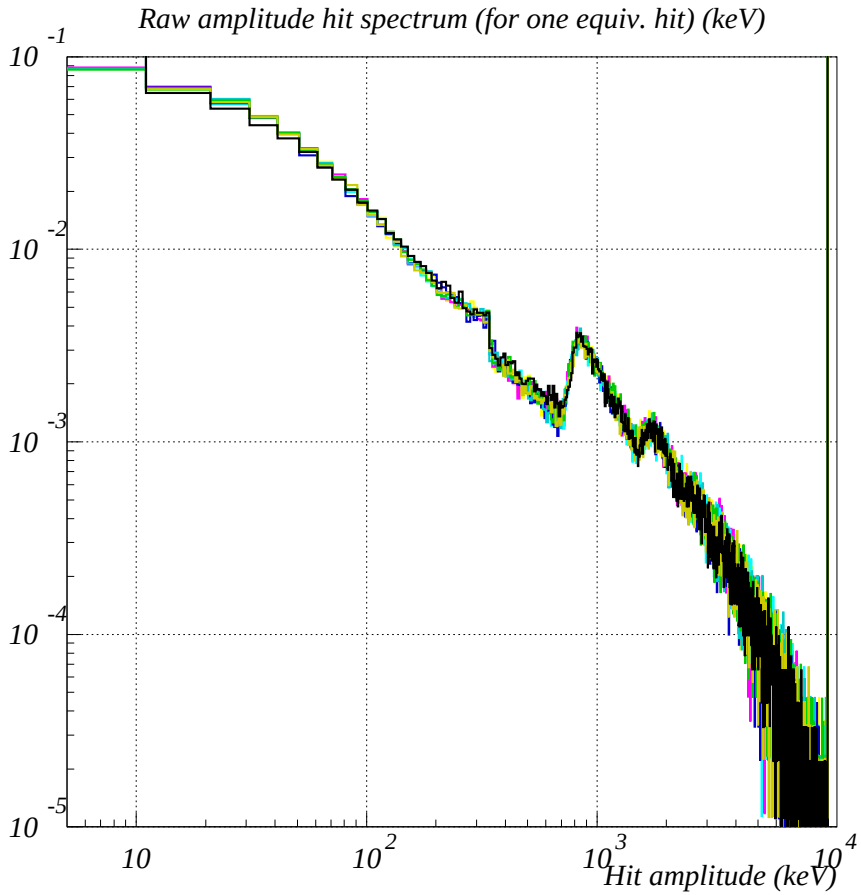


GEANT 4 only

Raw amplitude spectrum e 2 GeV

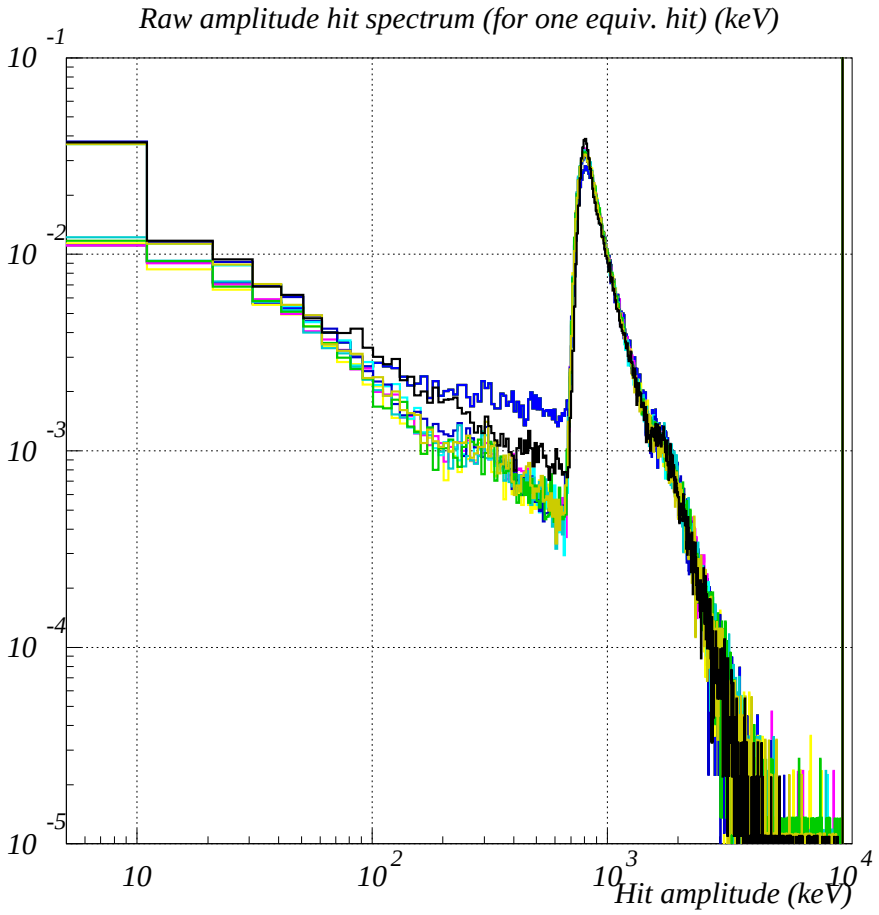


GEANT 3 only

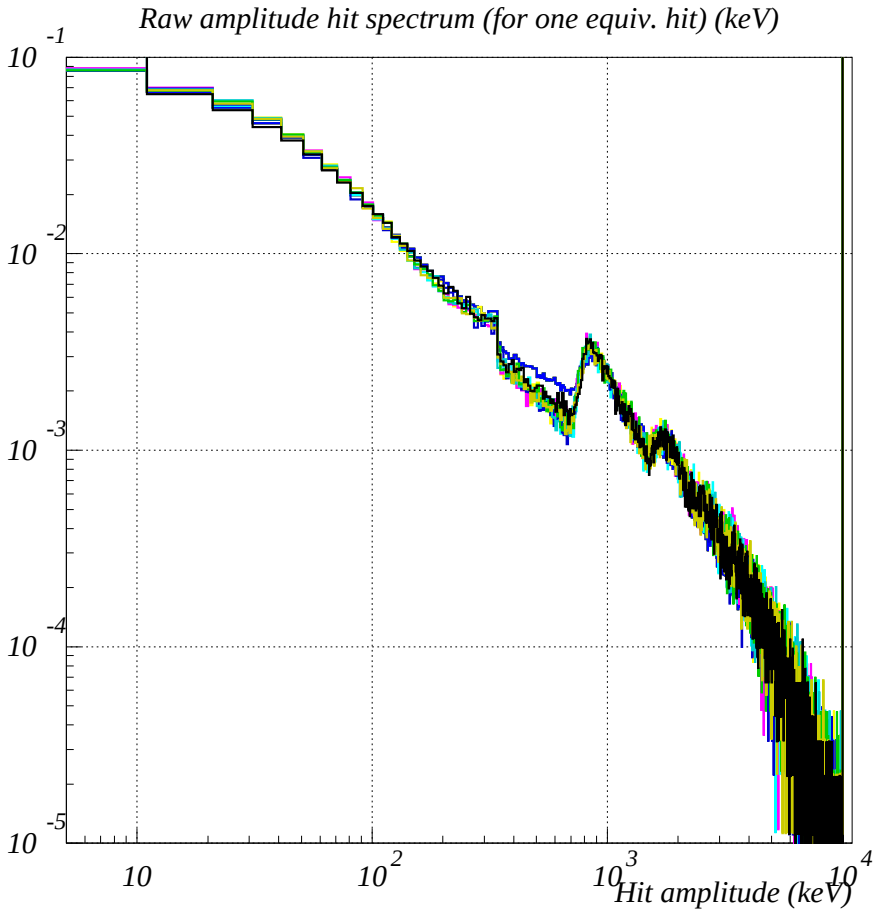


GEANT 4 only

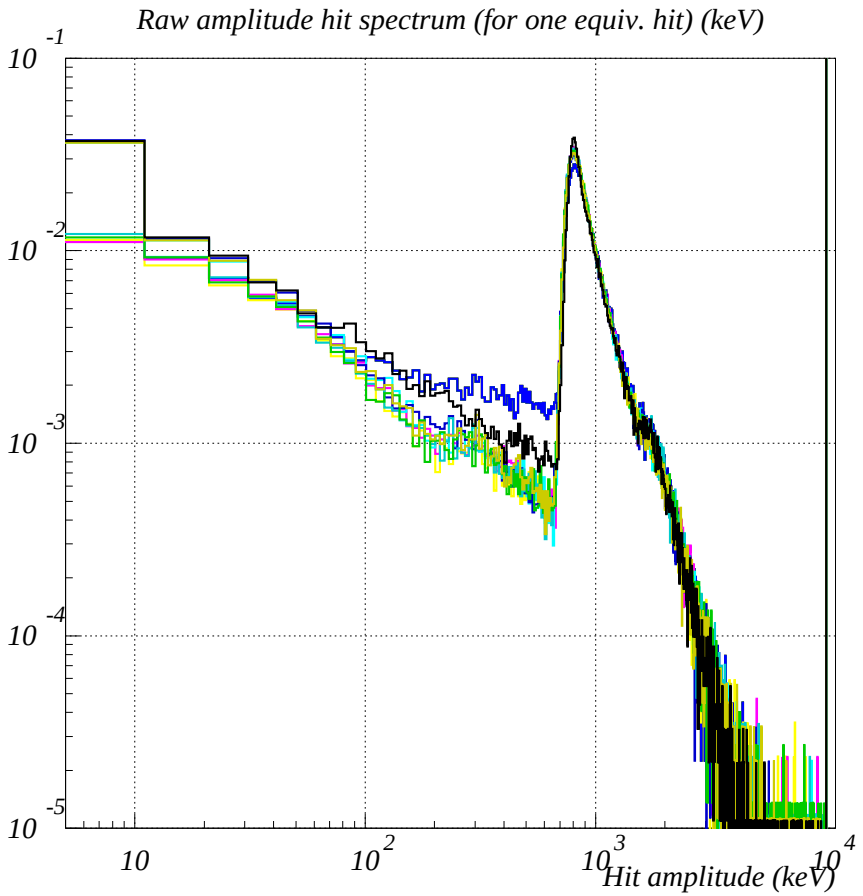
Raw amplitude spectrum, all together μ 2 GeV



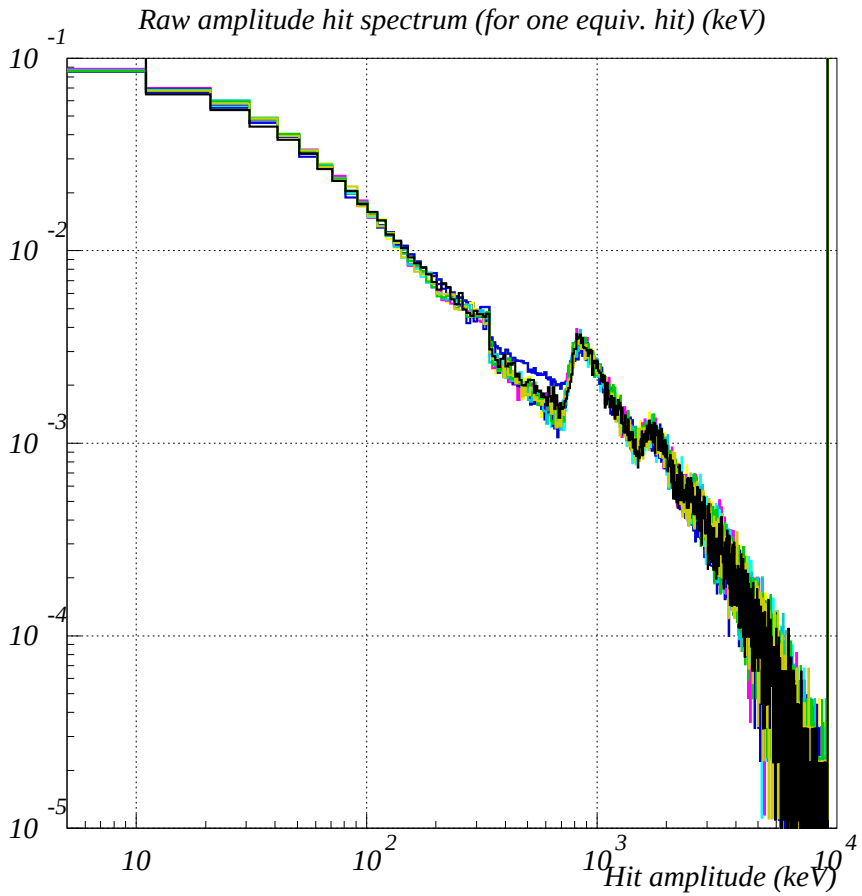
Raw amplitude spectrum, all together e 2 GeV



Raw amplitude spectrum, μ-, e-



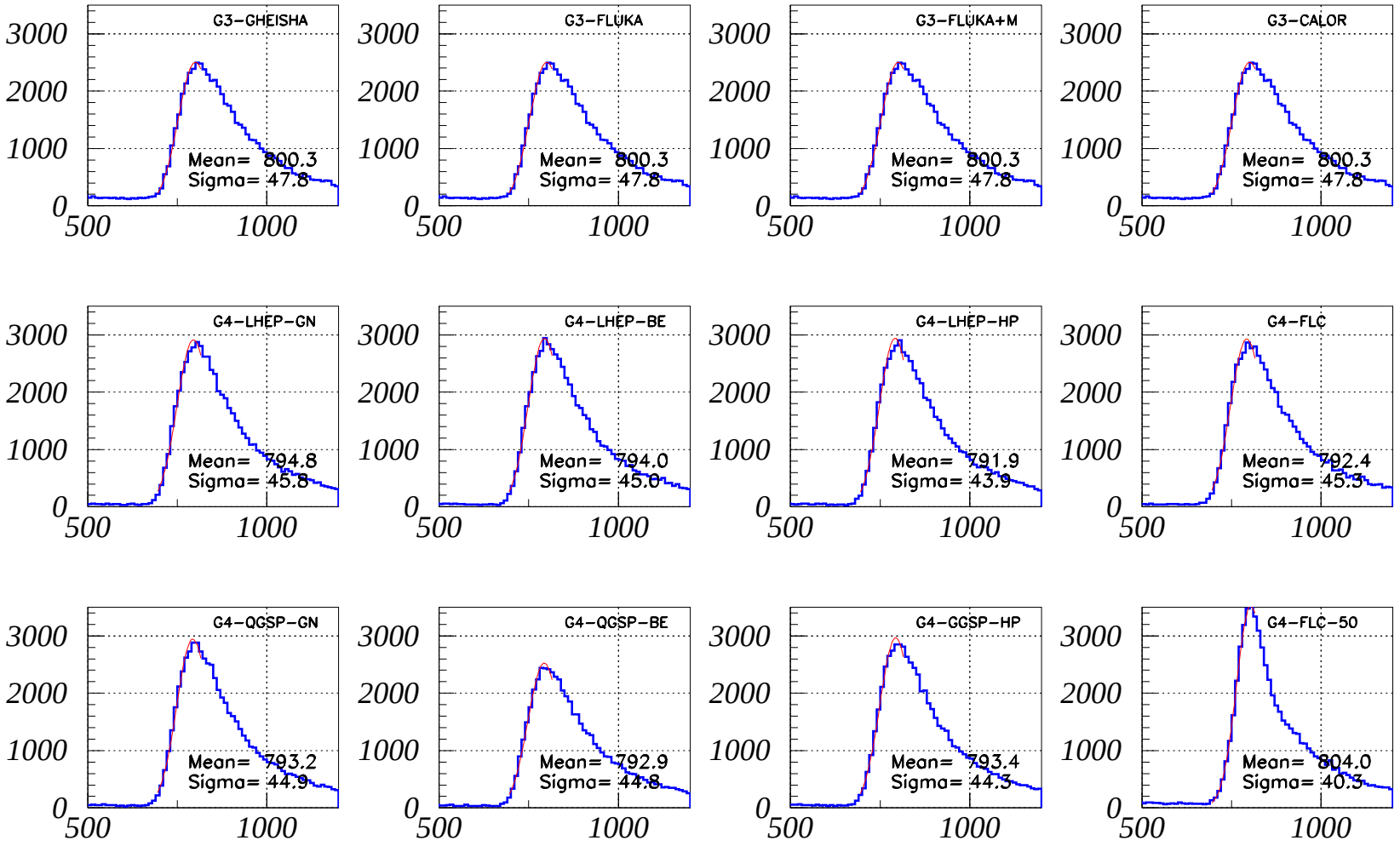
Muon 2 GeV



Electron 2 GeV

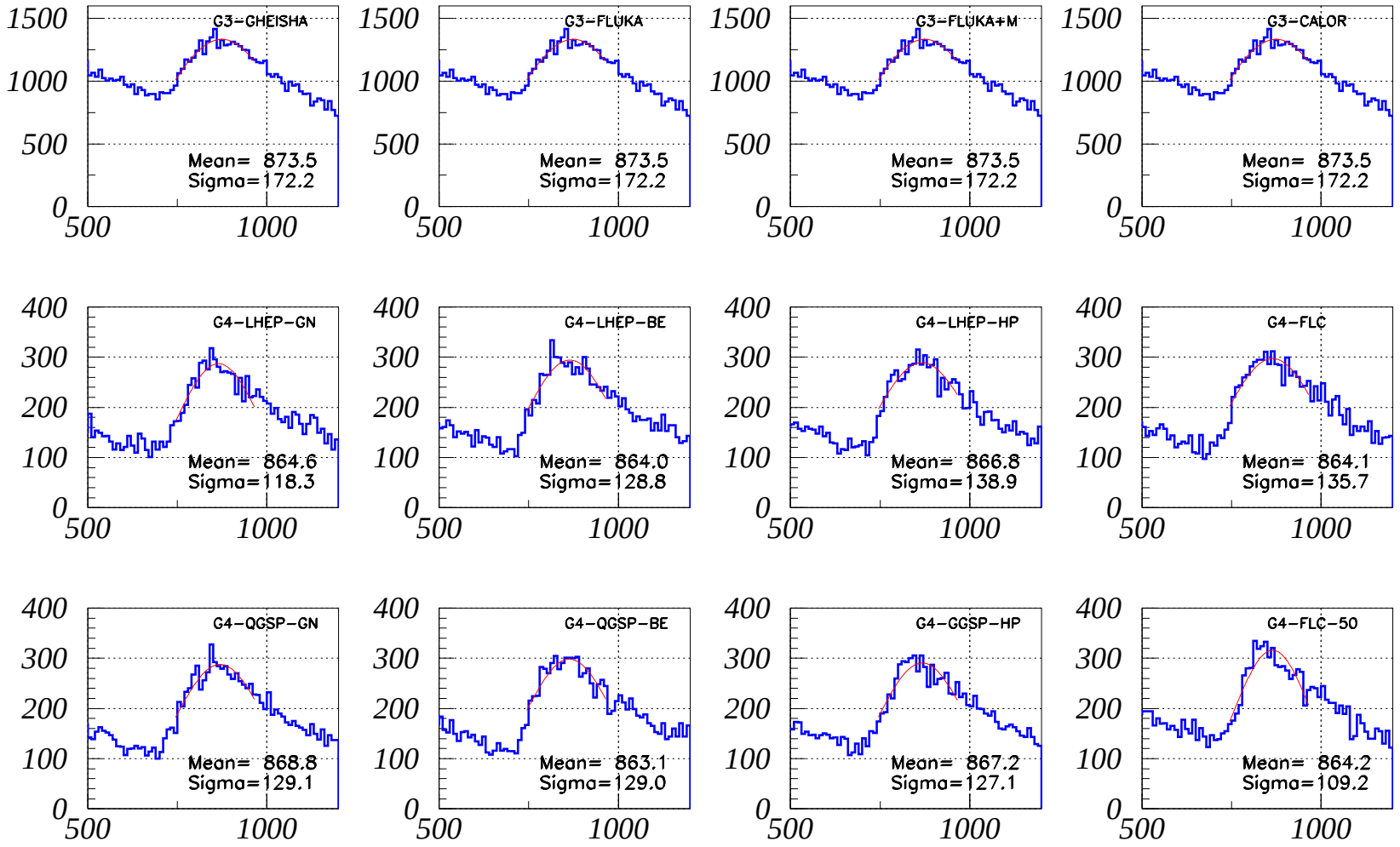
MIP Peak Close View μ 2 GeV

MIP pick position, close view (keV)

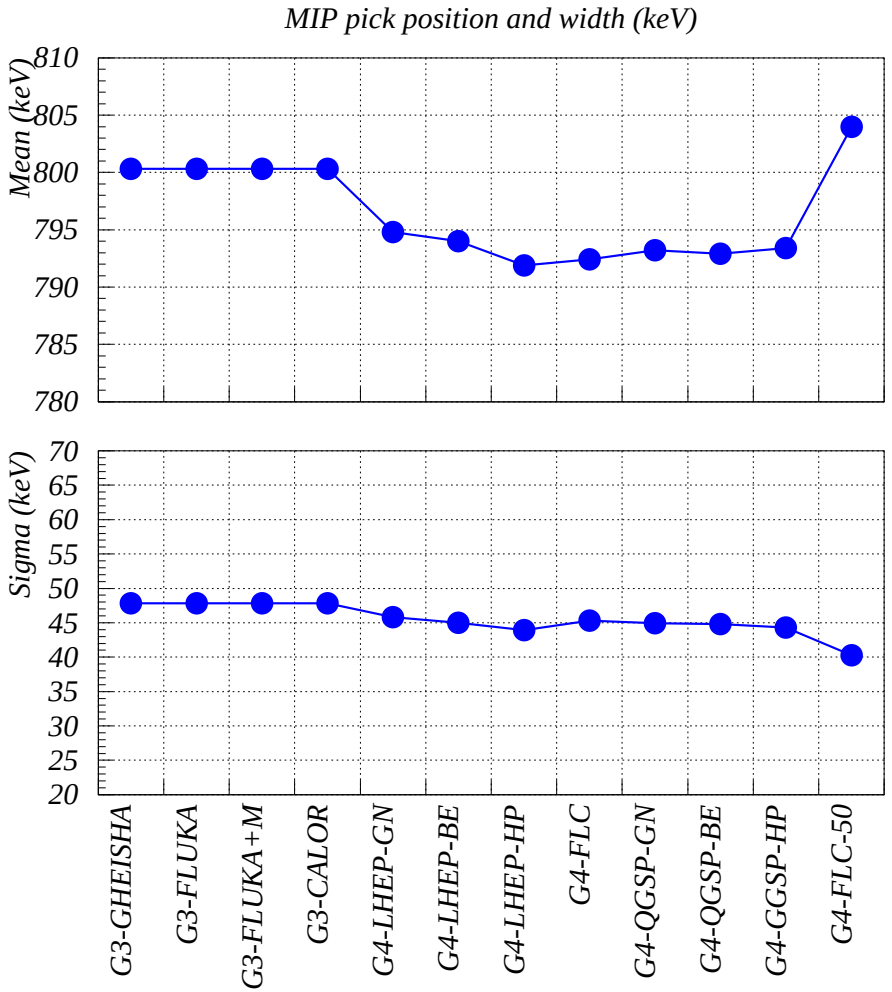


MIP Peak Close View e 2 GeV

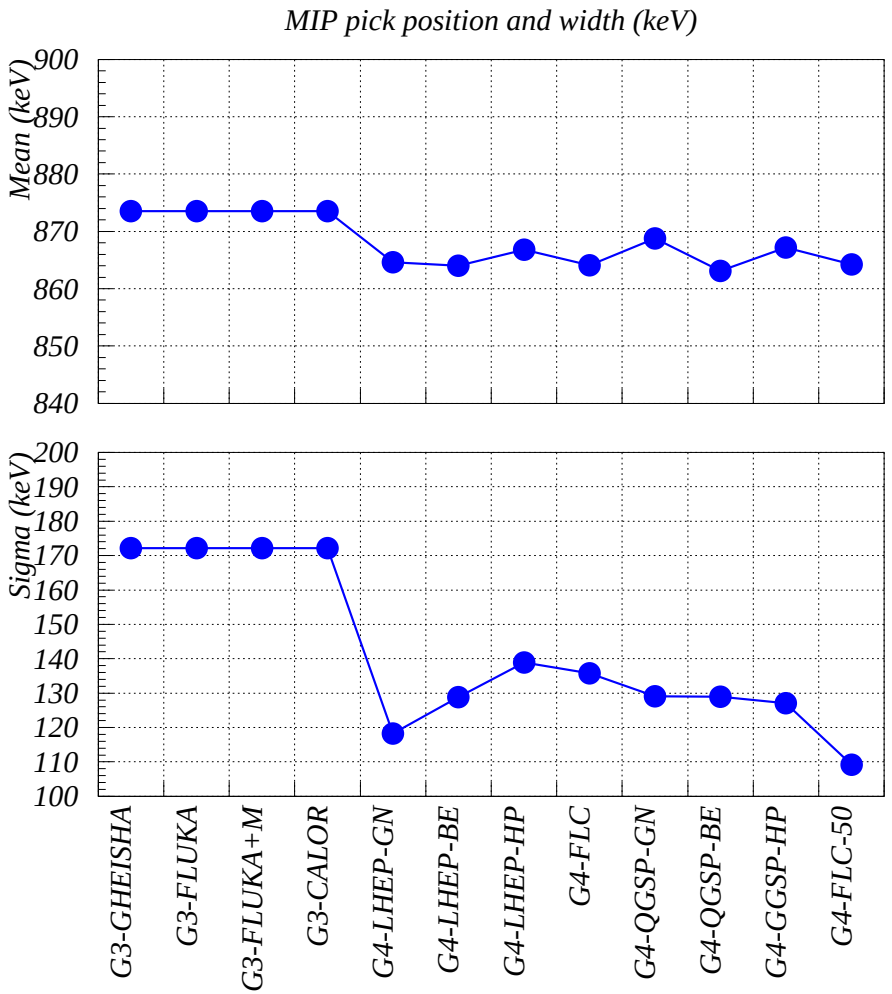
MIP pick position, close view (keV)



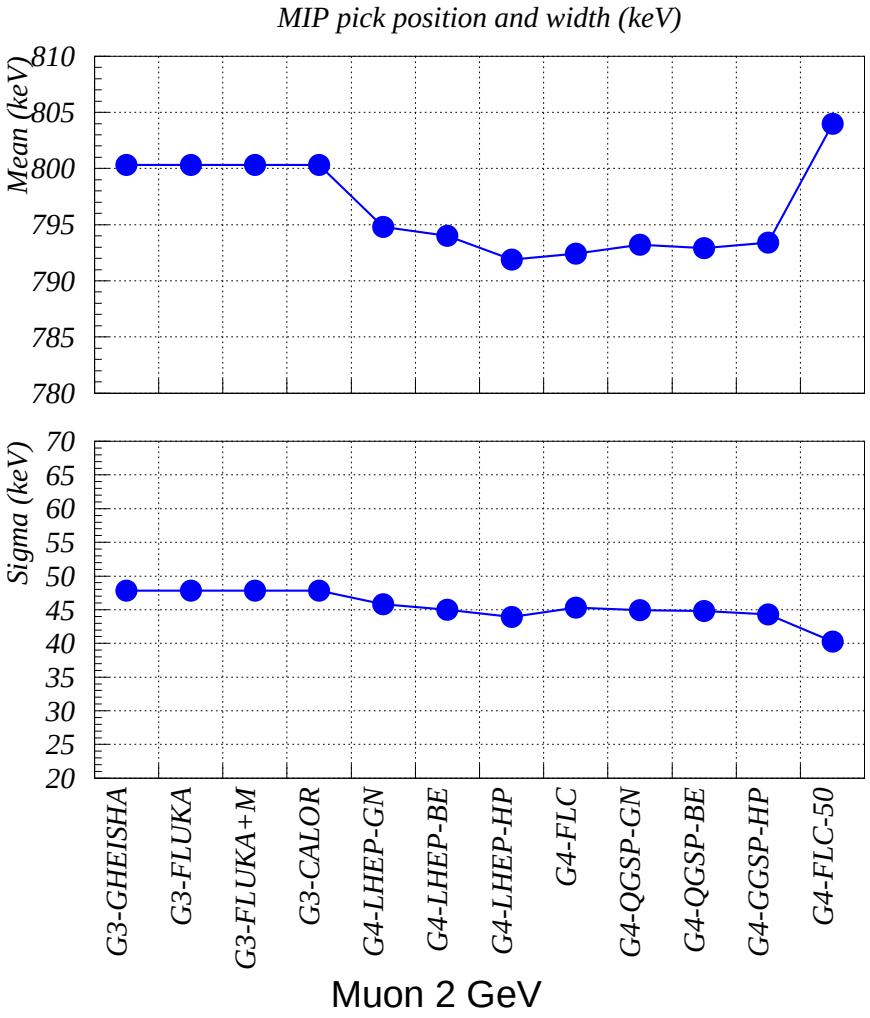
MIP Position μ 2 GeV



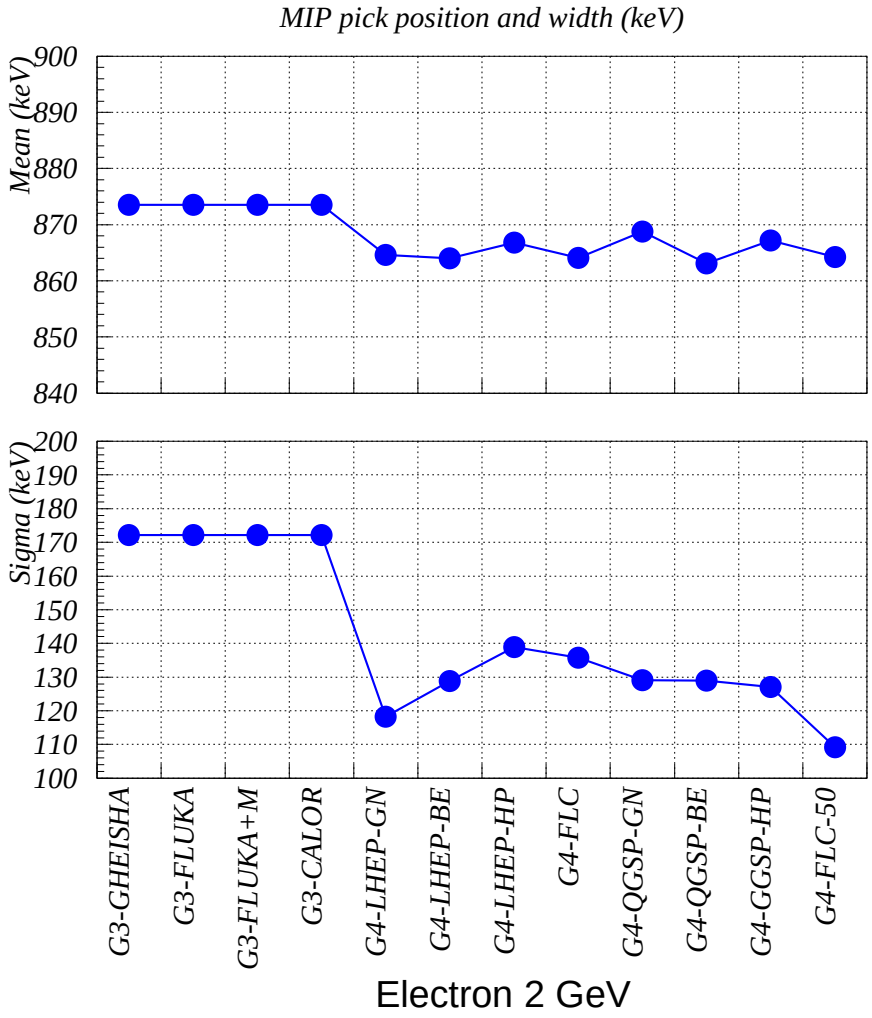
MIP Position e 2 GeV



MIP Position and Width, μ-, e-

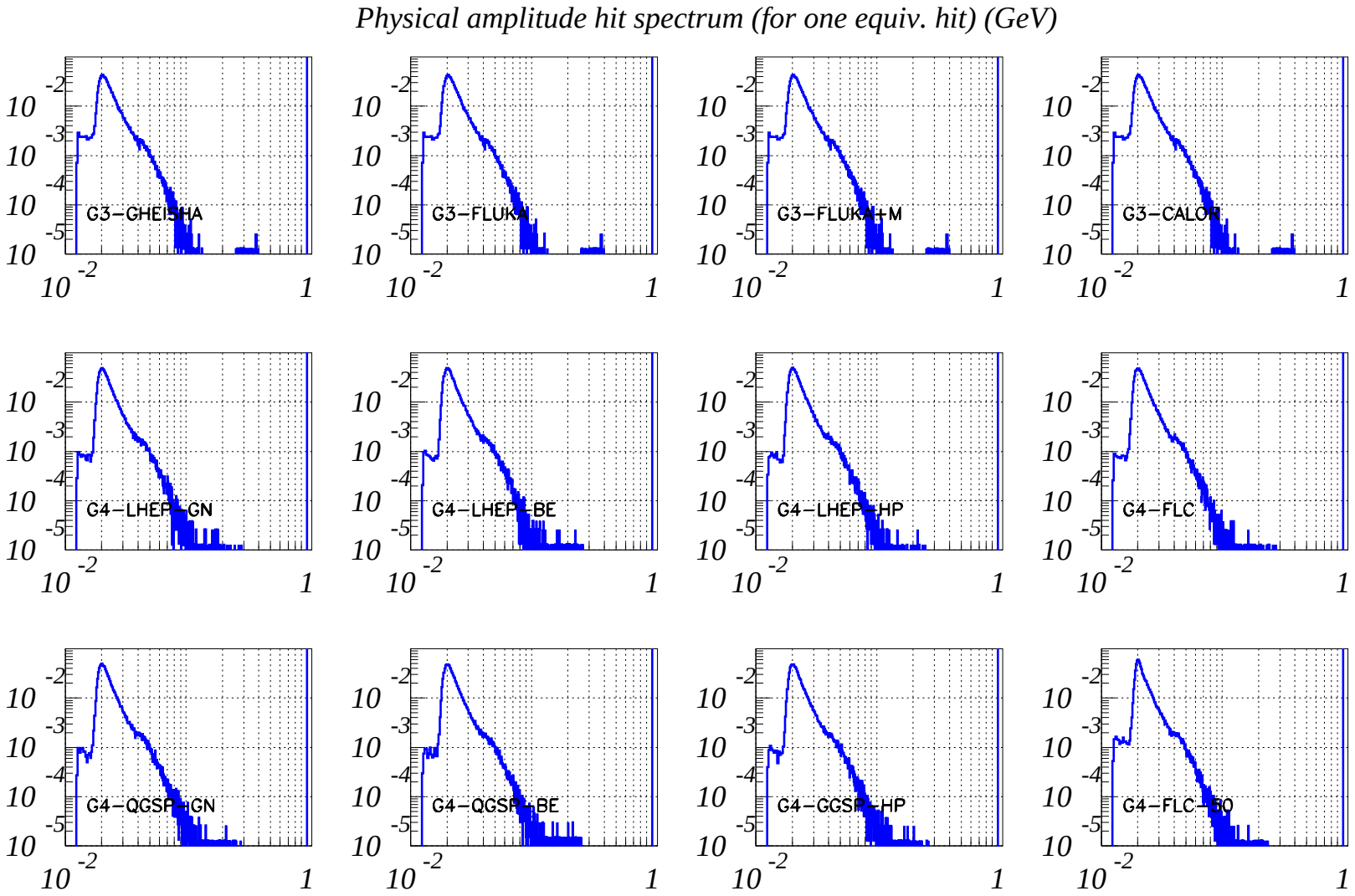


Muon 2 GeV

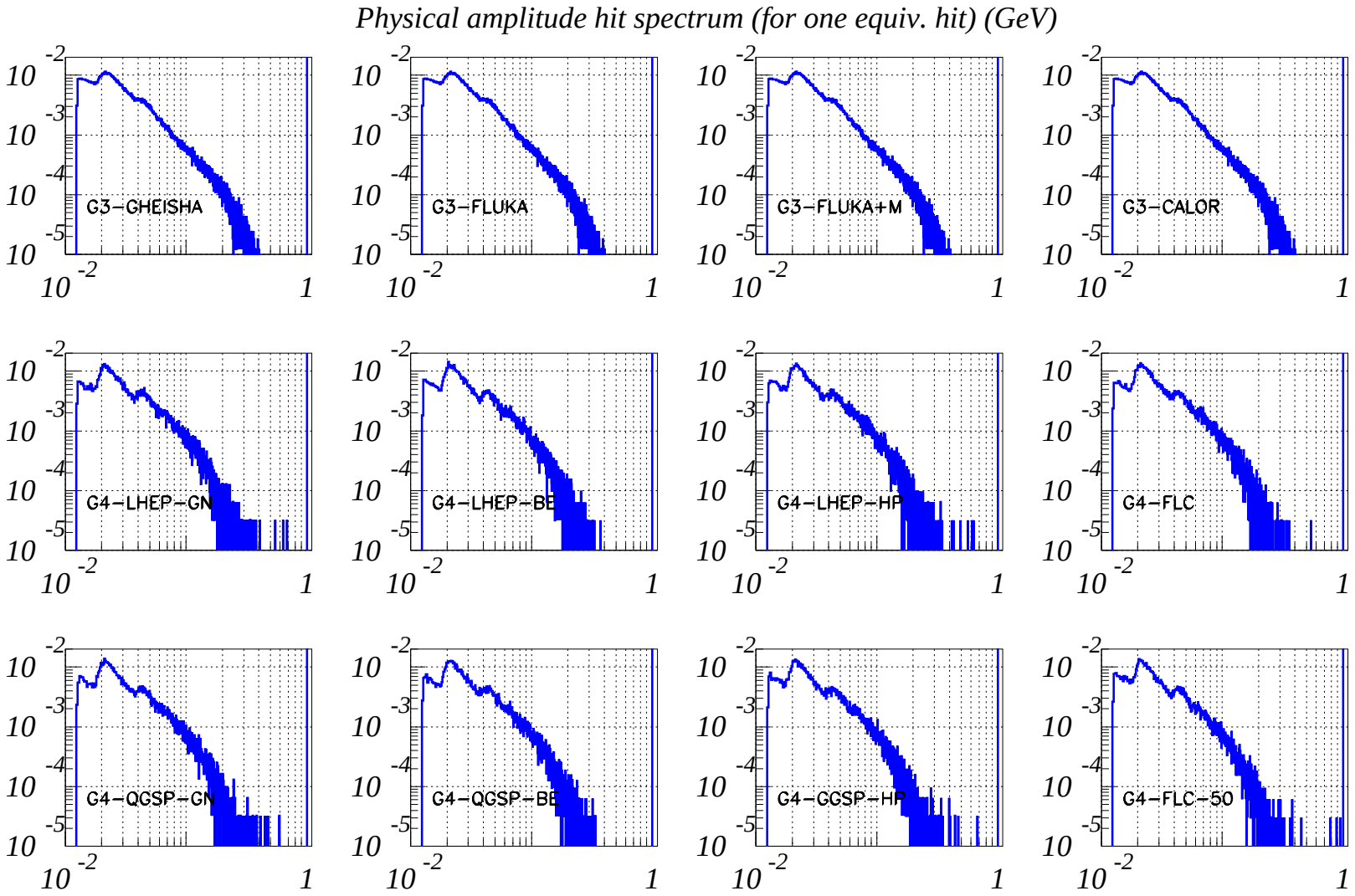


Electron 2 GeV

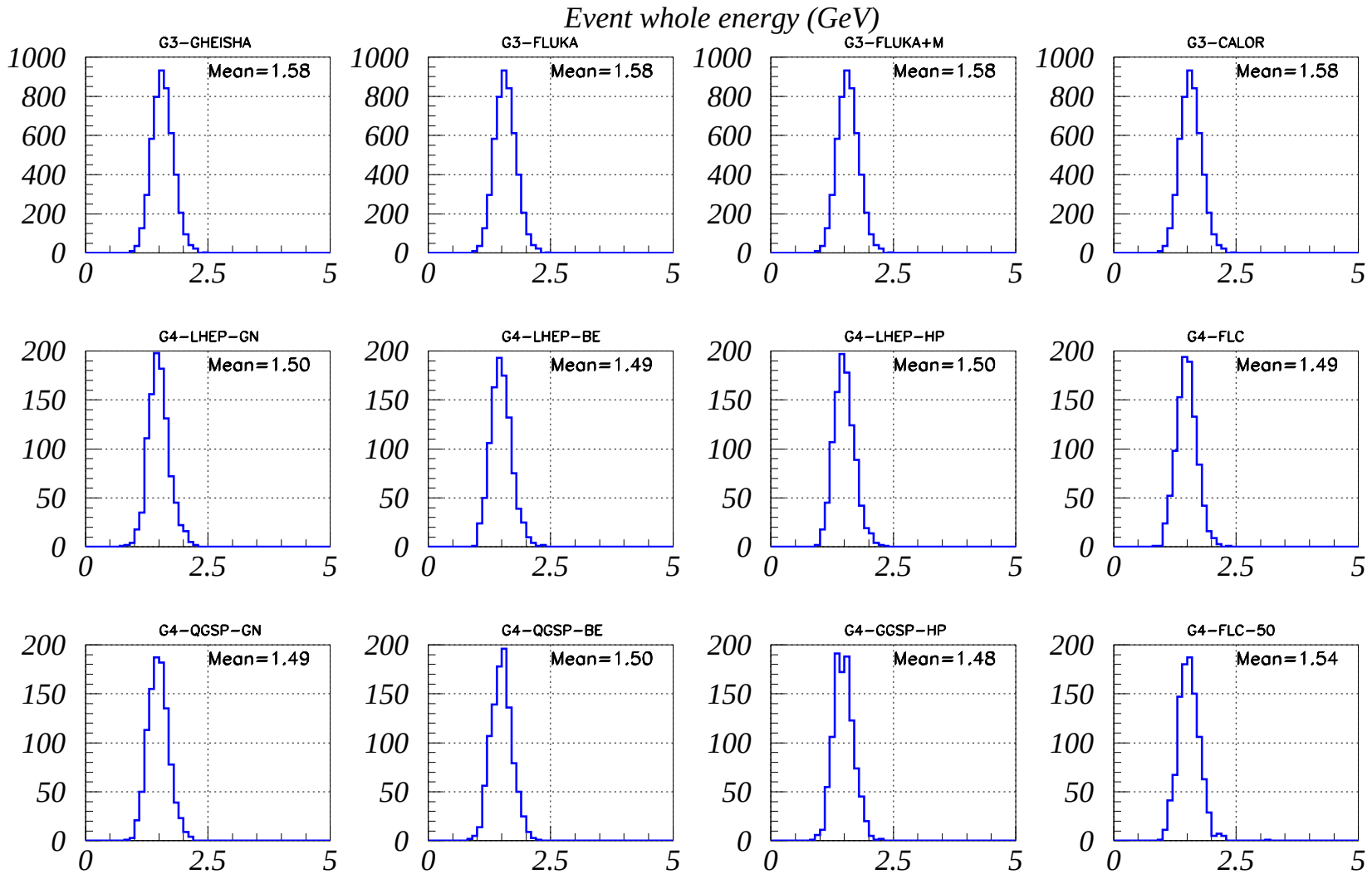
Physical Amplitude Hit Spectrum μ 2 GeV



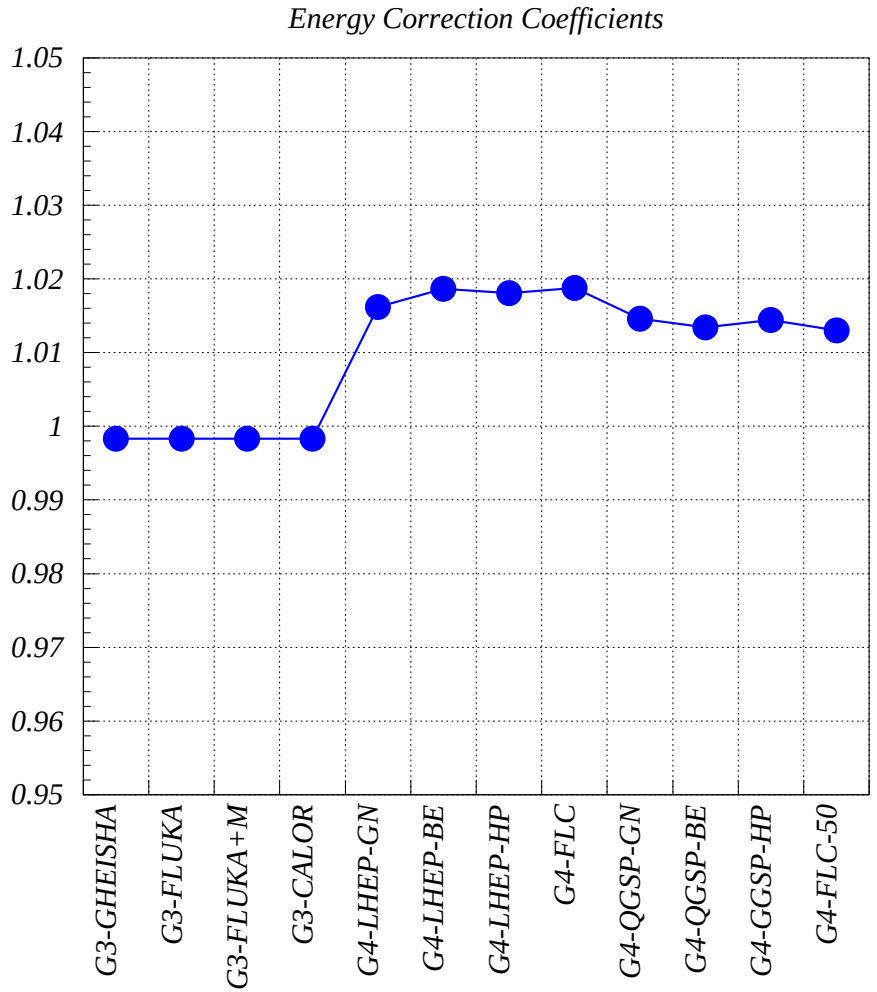
Physical Amplitude Hit Spectrum e 2 GeV



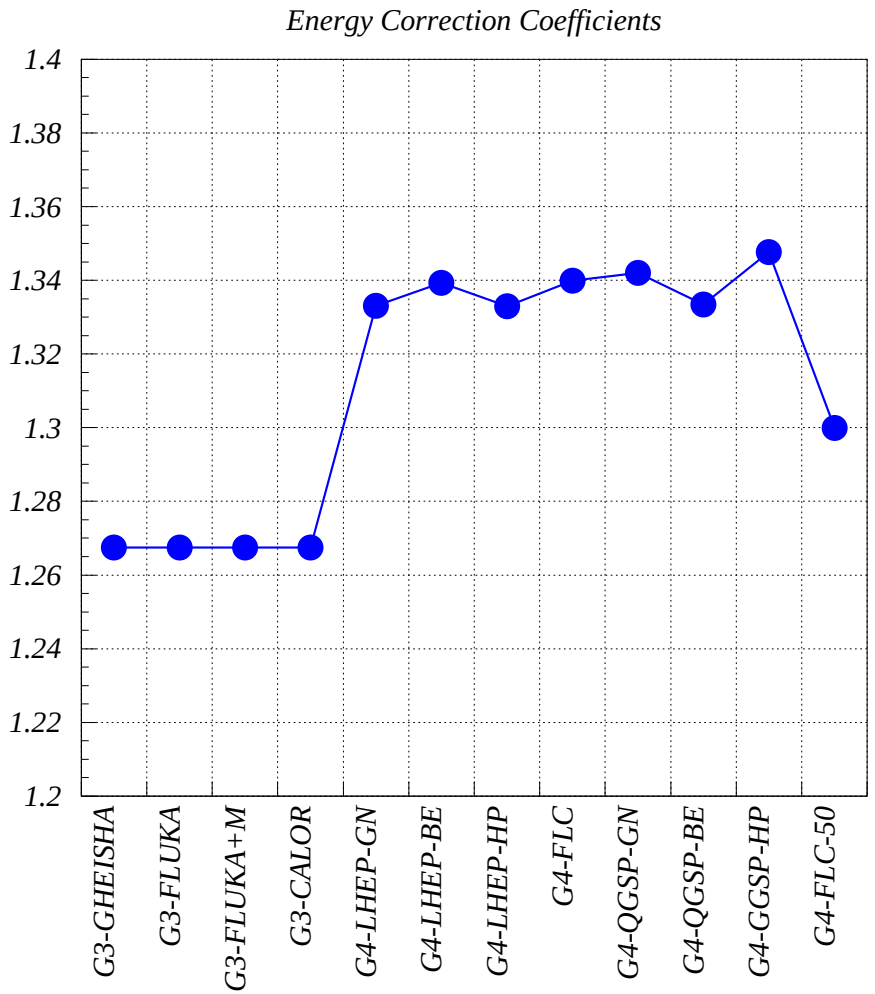
Whole Energy Spectrum e 2 GeV



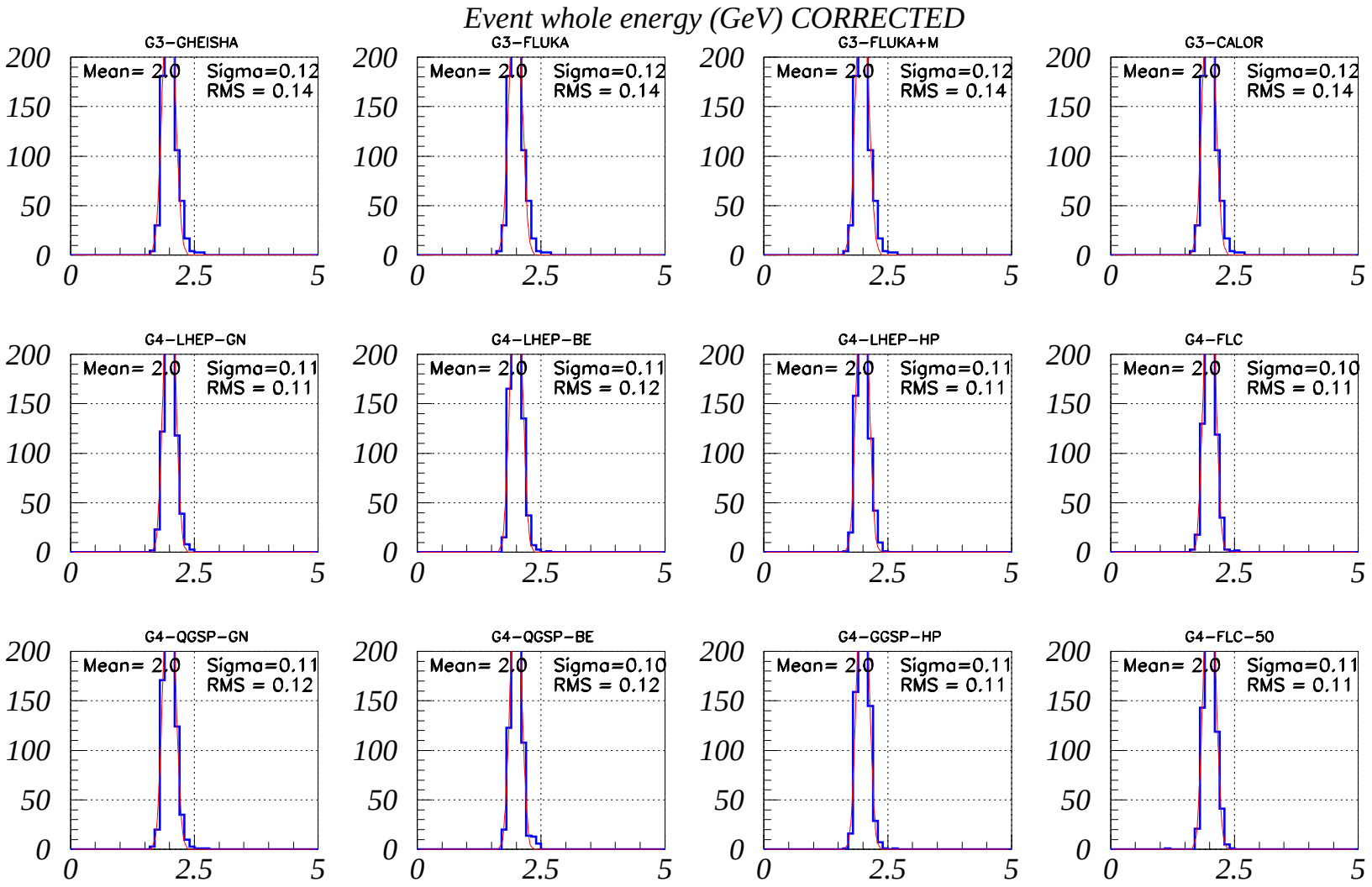
Energy Correction Factor μ 2 GeV



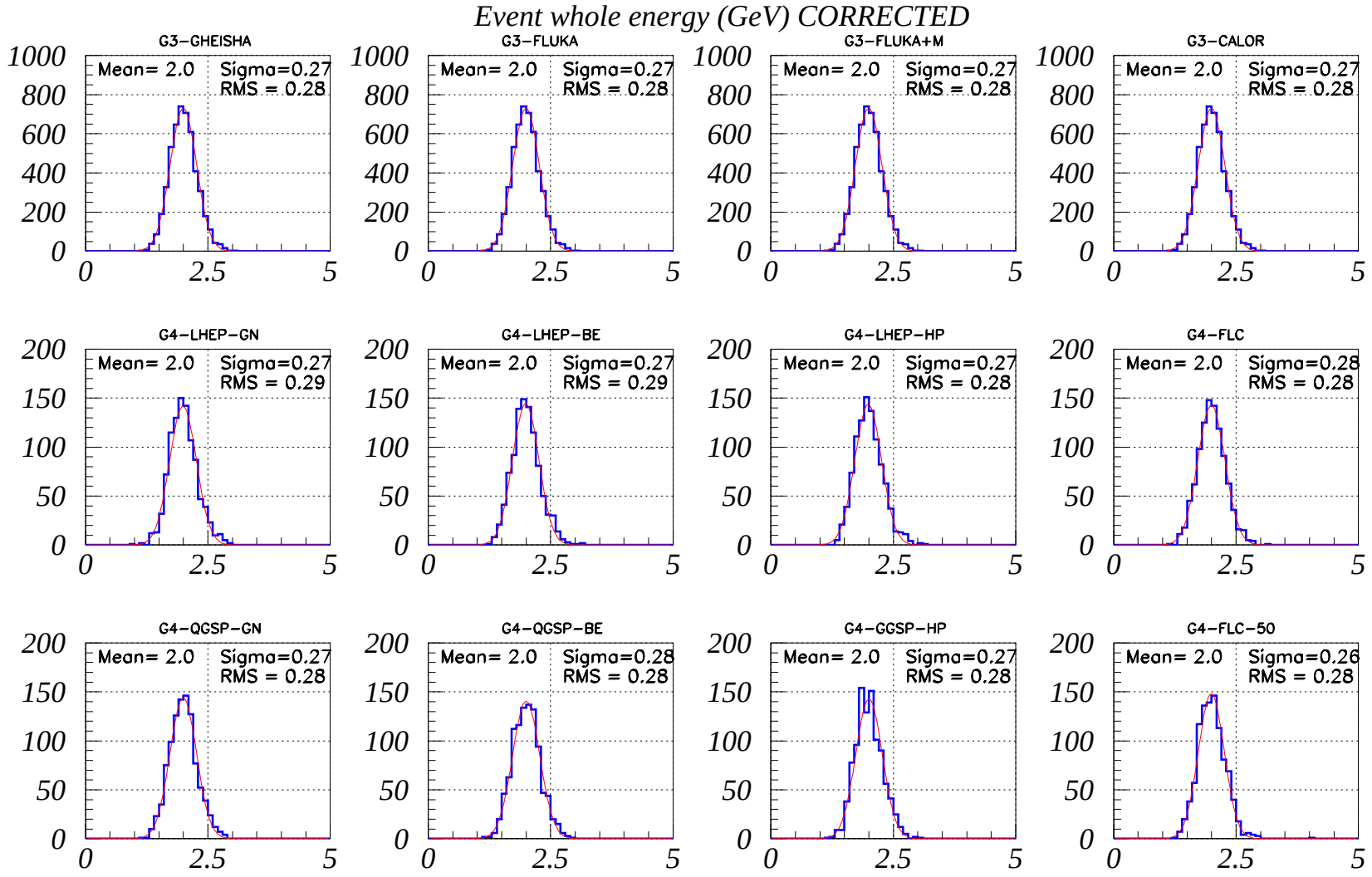
Energy Correction Factor e 2 GeV



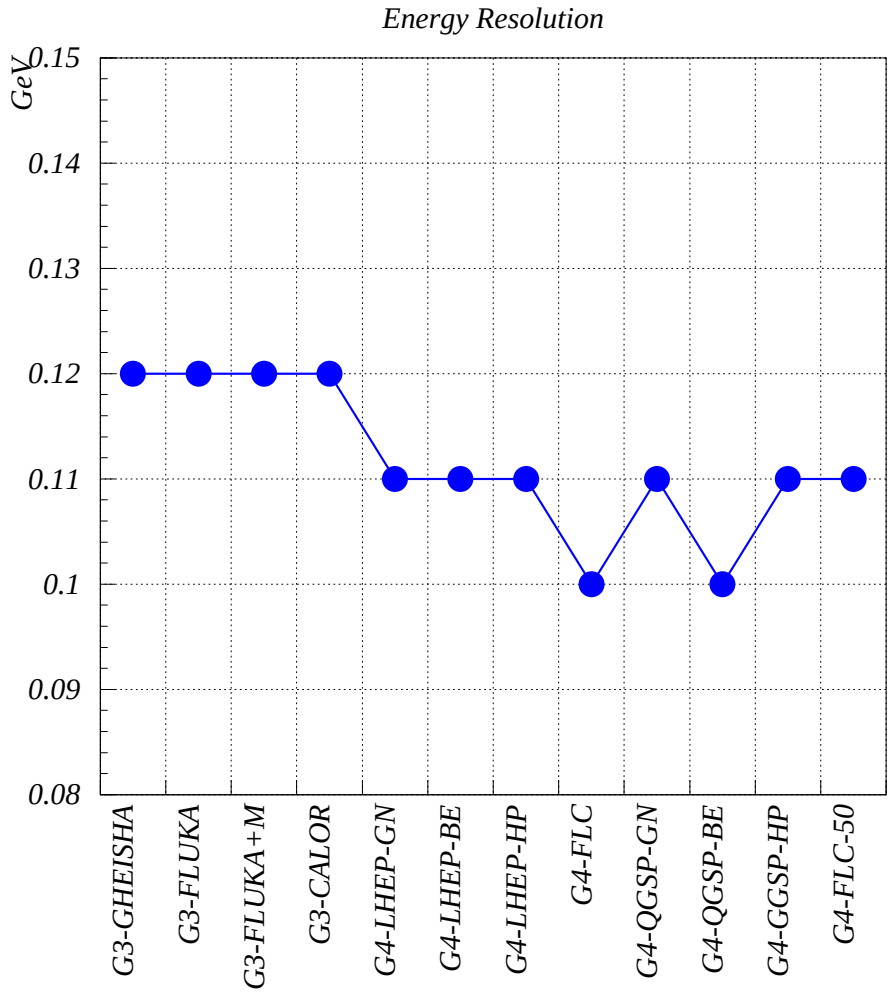
Corrected Energy Spectrum μ 2 GeV



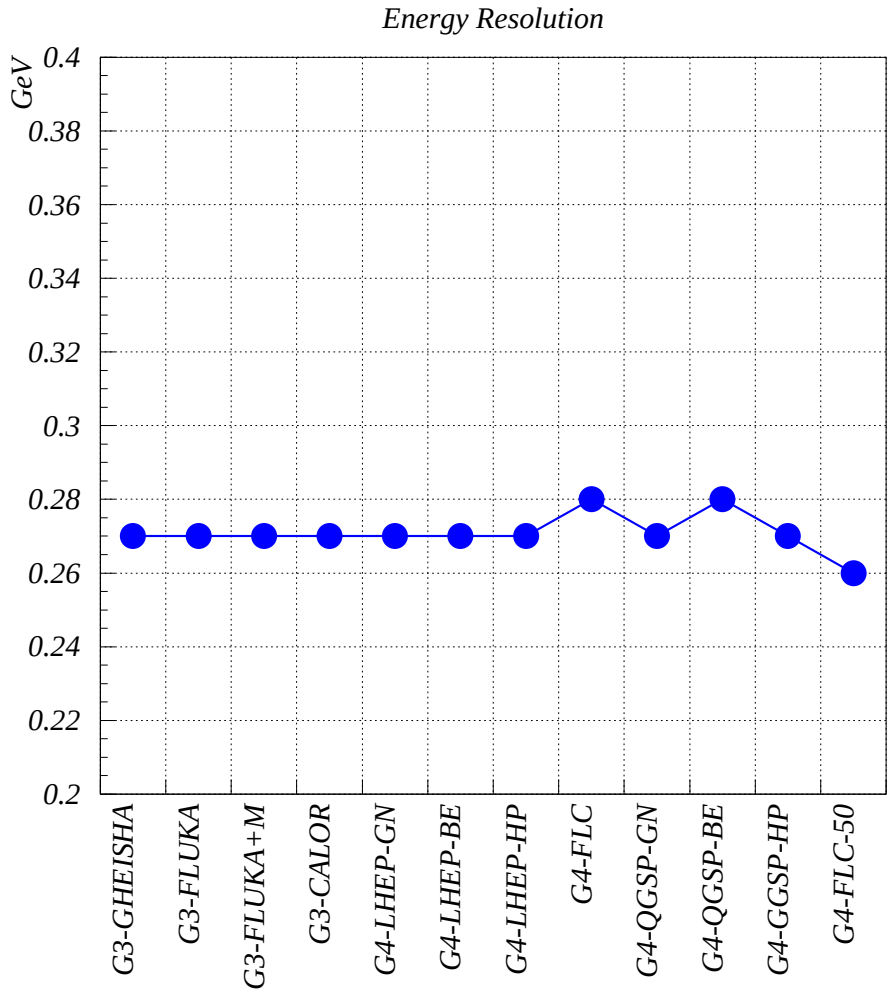
Corrected Energy Spectrum e 2 GeV



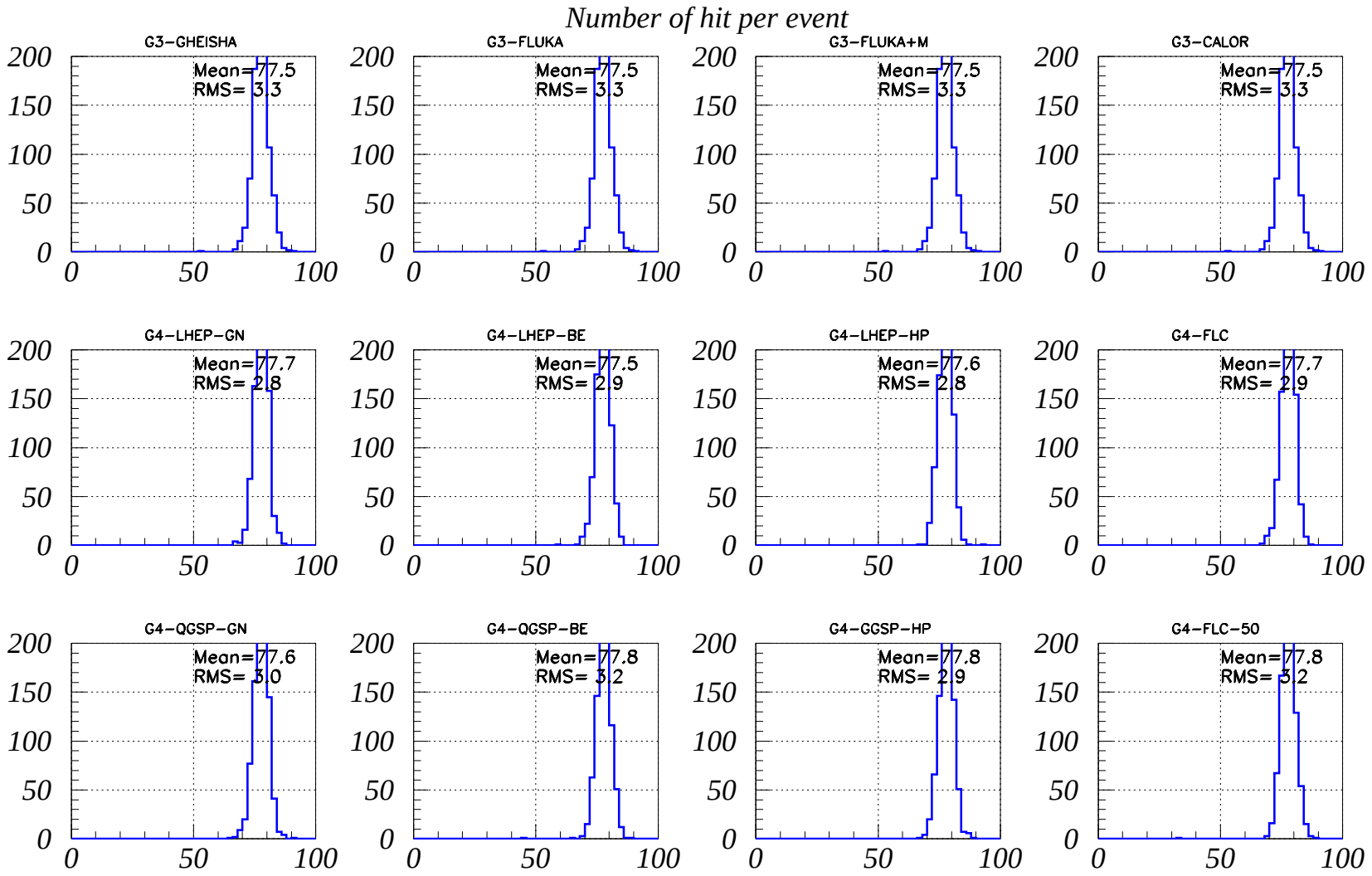
Energy Resolution μ 2 GeV



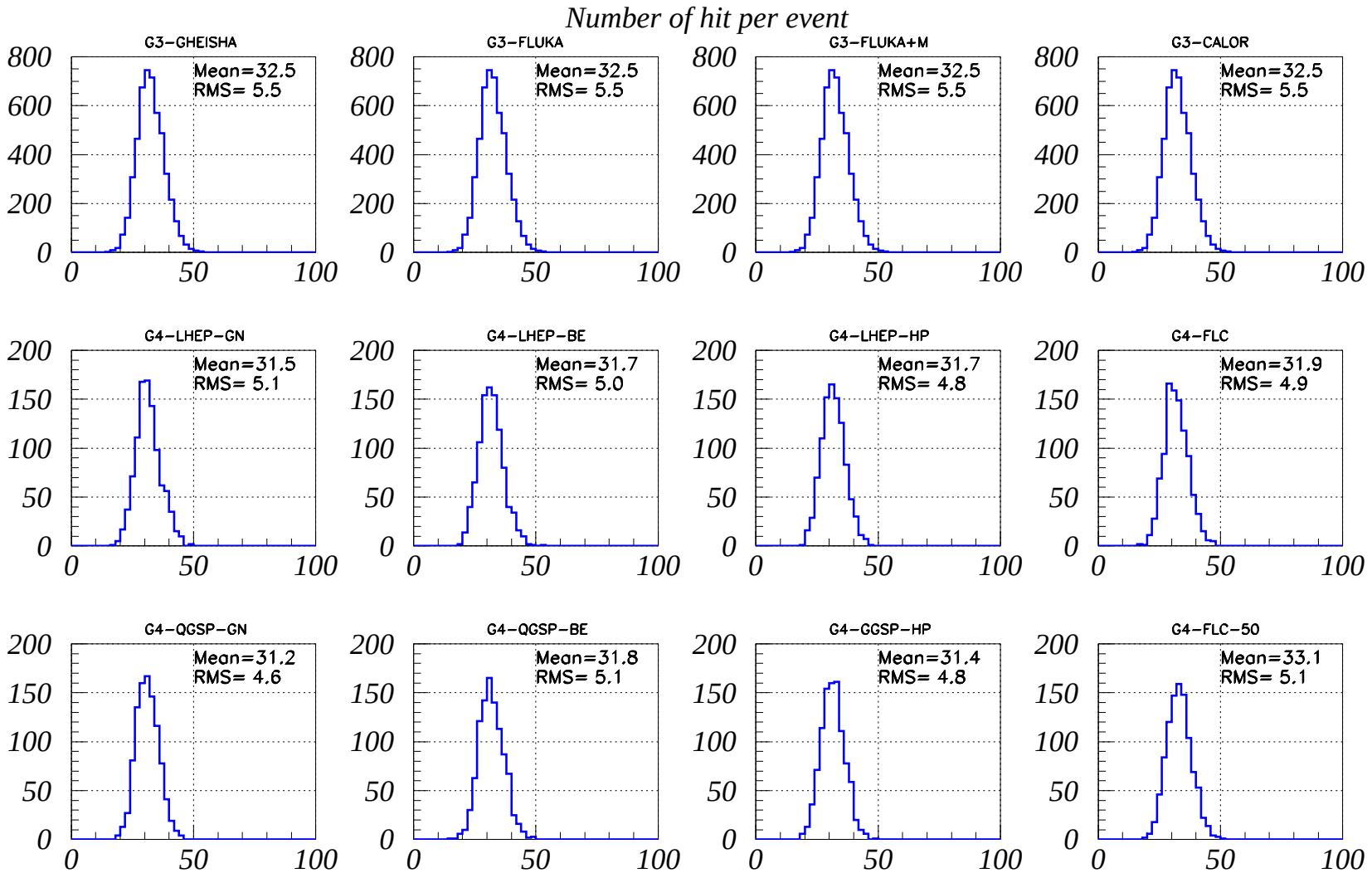
Energy Resolution e 2 GeV



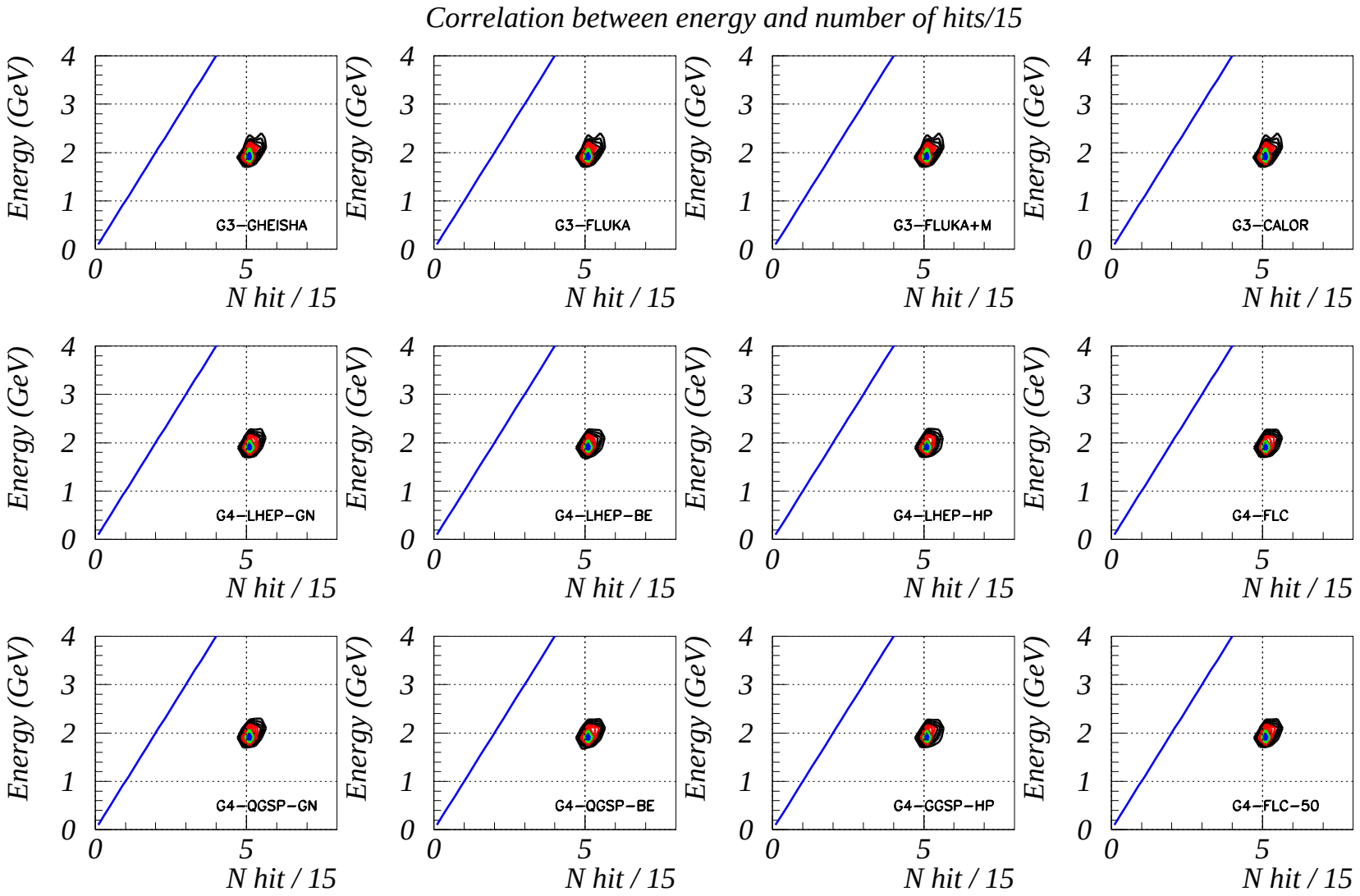
Hit Number per Event μ 2 GeV



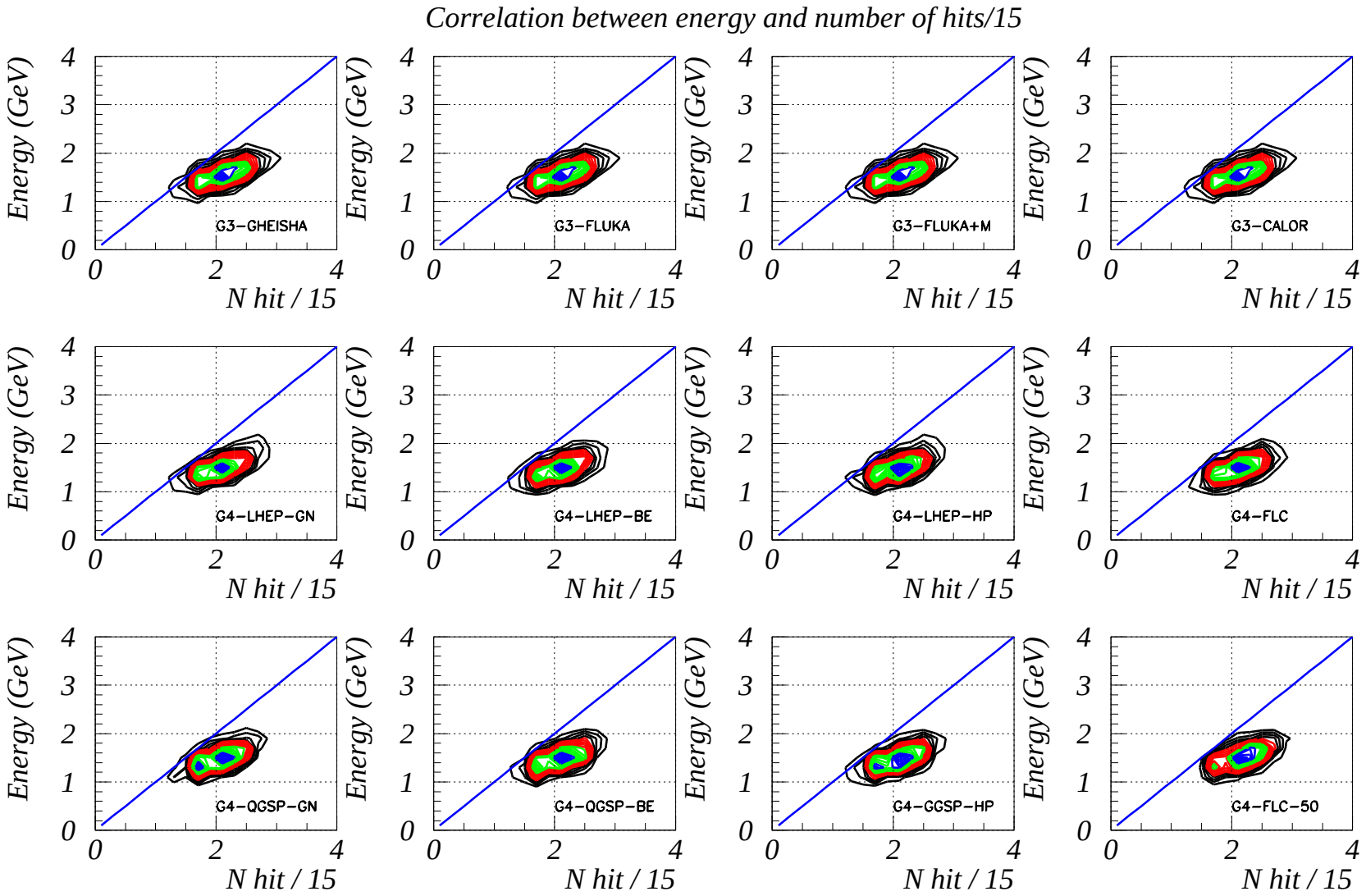
Hit Number per Event e 2 GeV



Event Energy VS Number of hits μ 2 GeV

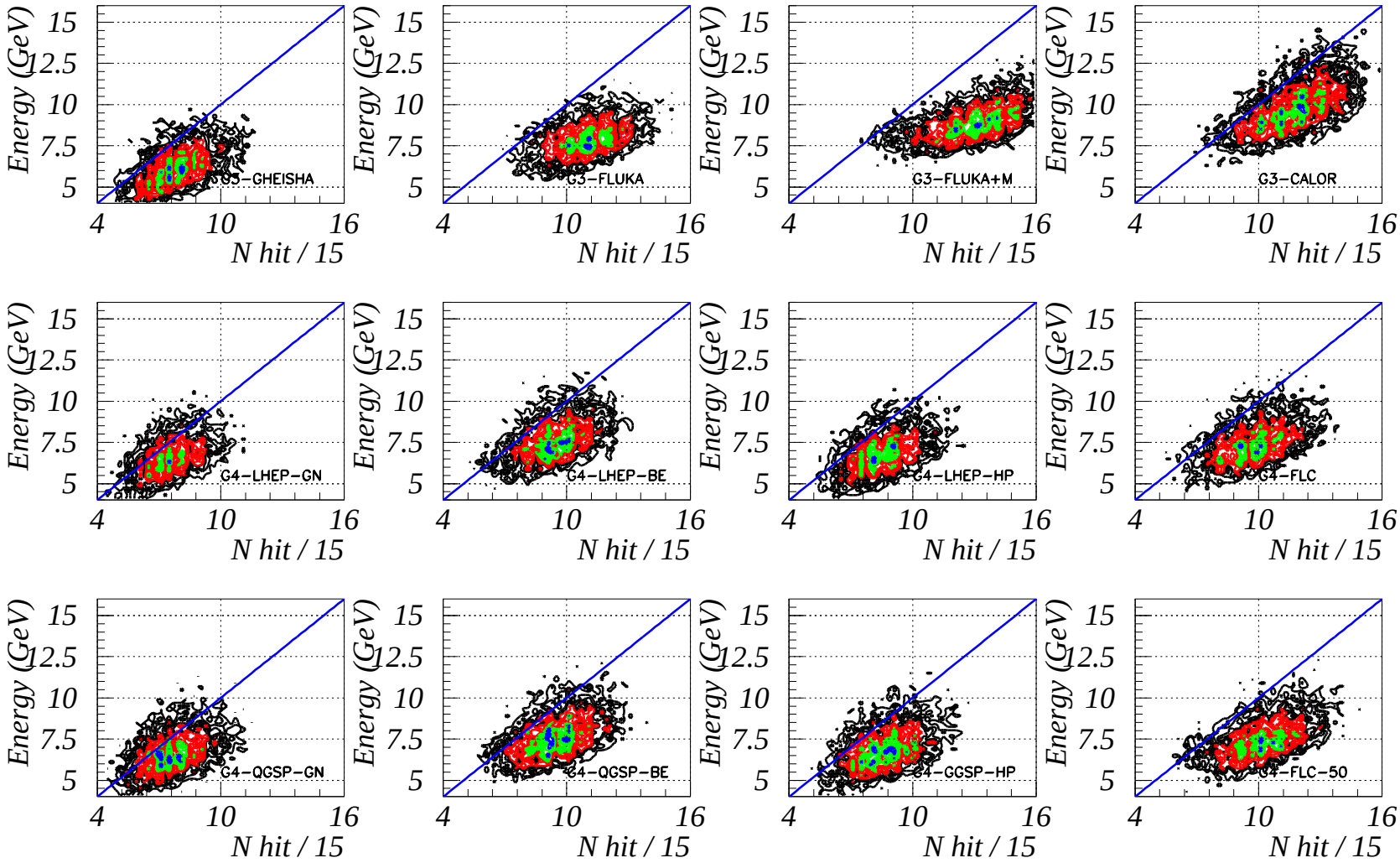


Event Energy VS Number of hits e 2 GeV

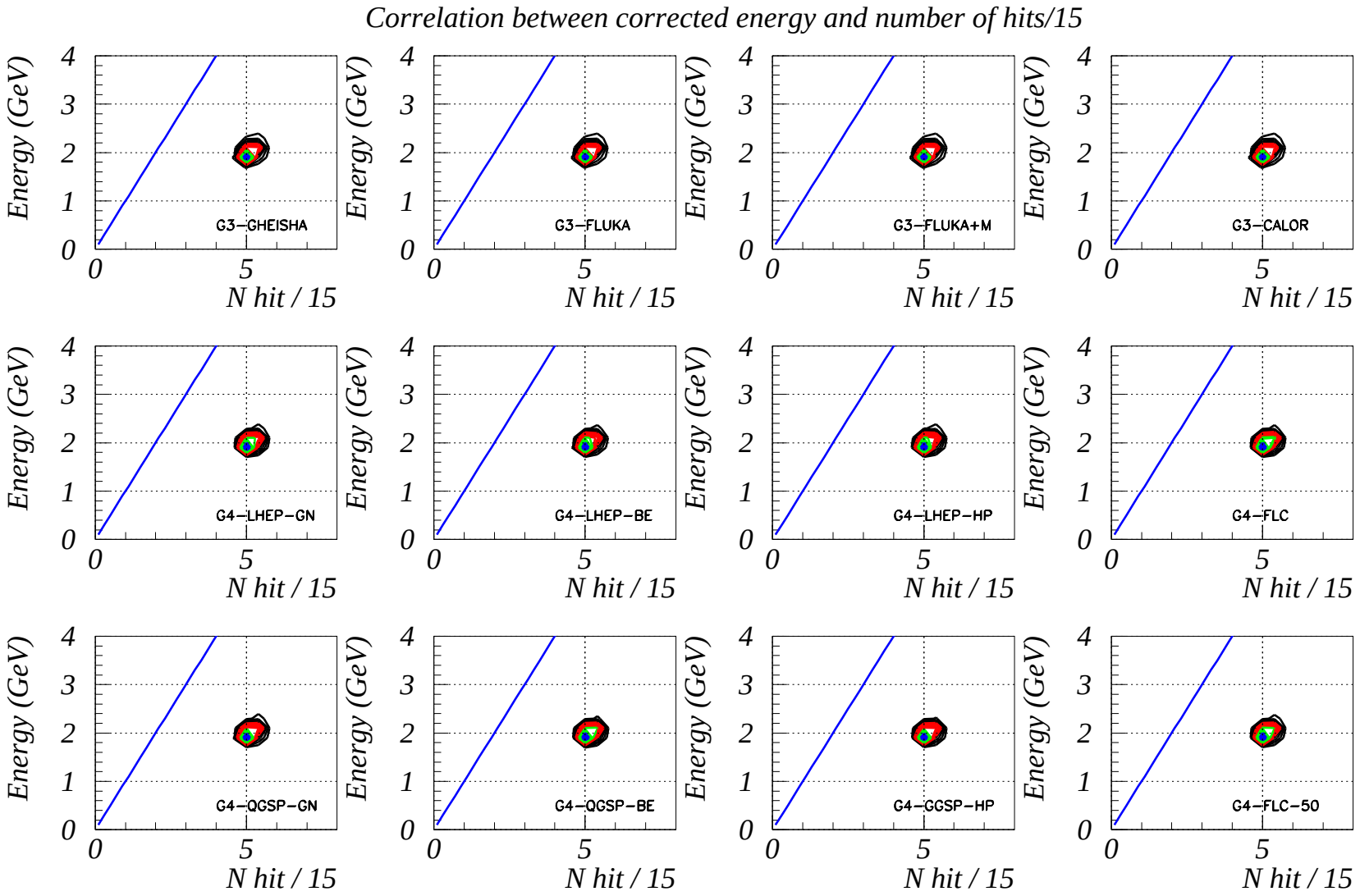


Event Energy VS Number of hits π 10 GeV

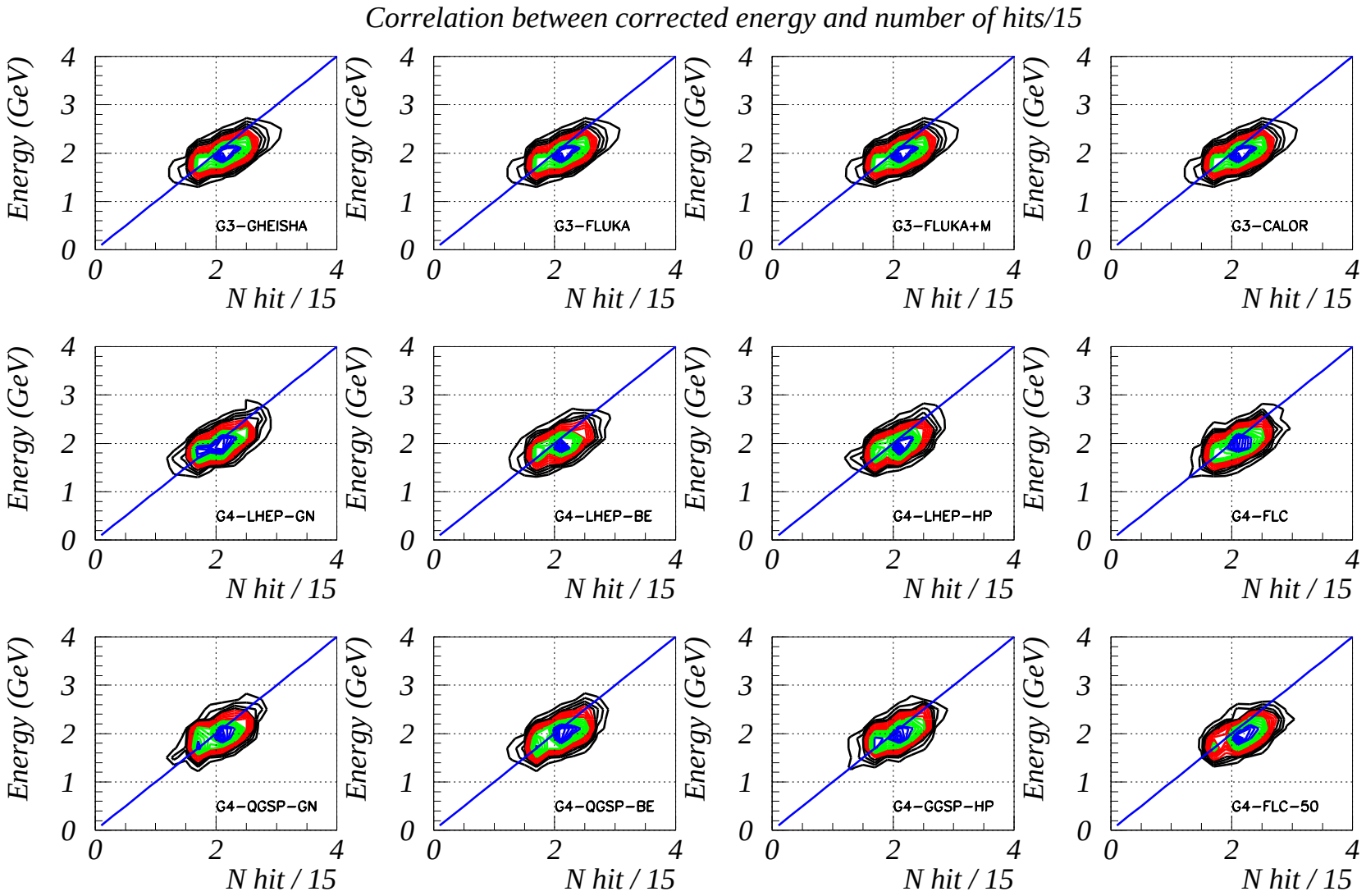
Correlation between energy and number of hits/15



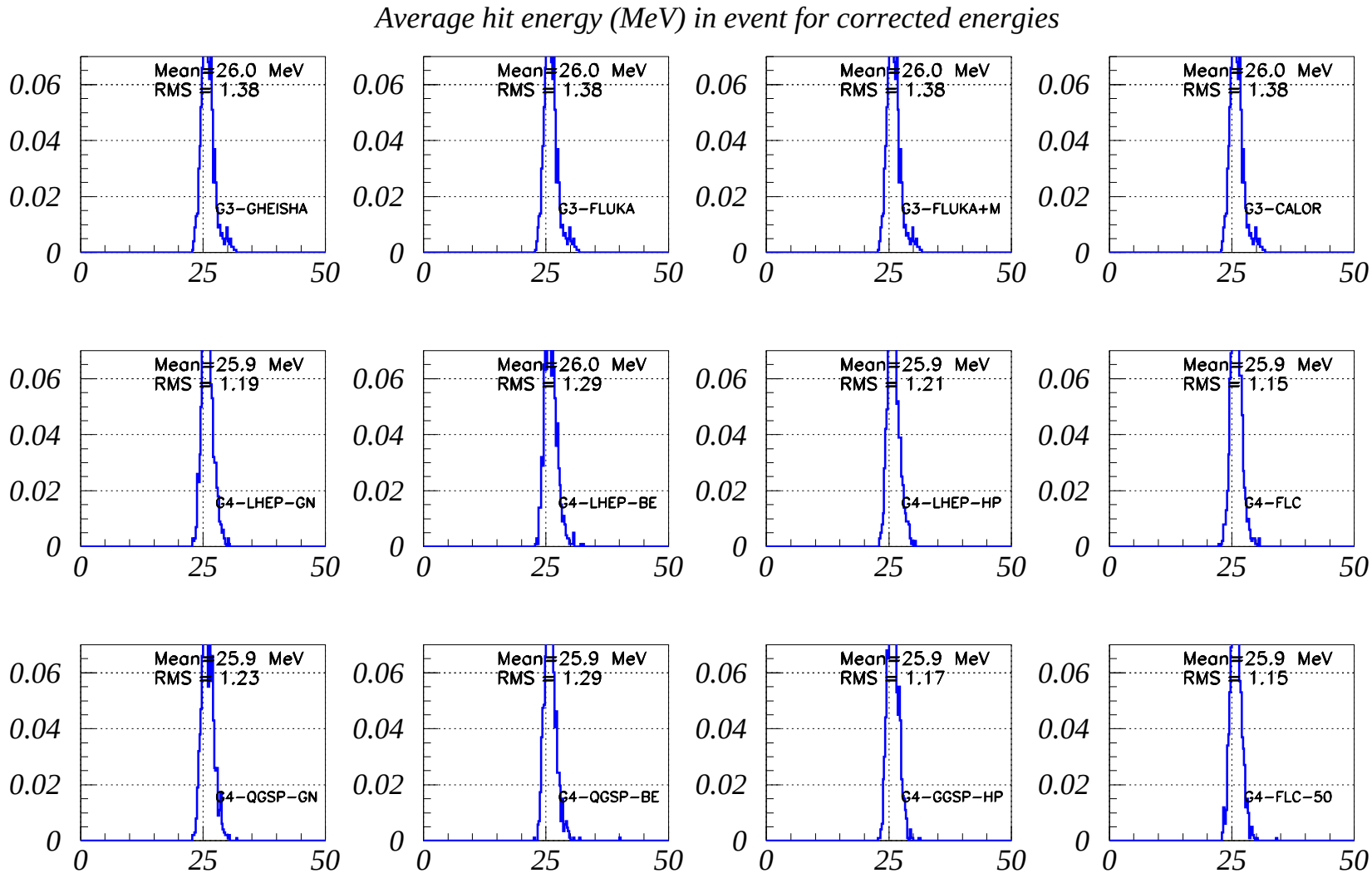
Event Energy Corrected VS Number of hits μ 2 GeV



Event Energy Corrected VS Number of hits e 2 GeV

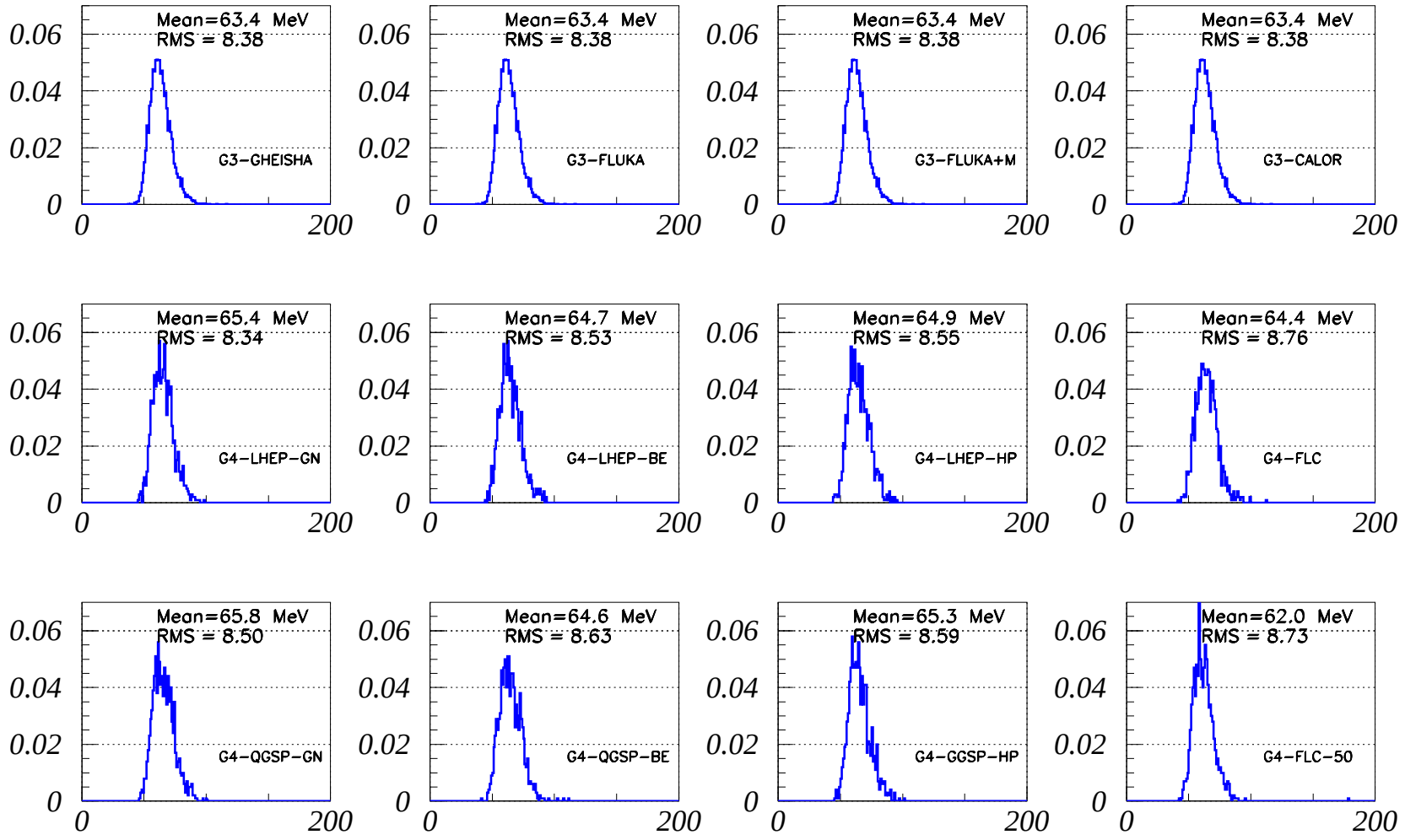


Average Hit Energy μ 2 GeV

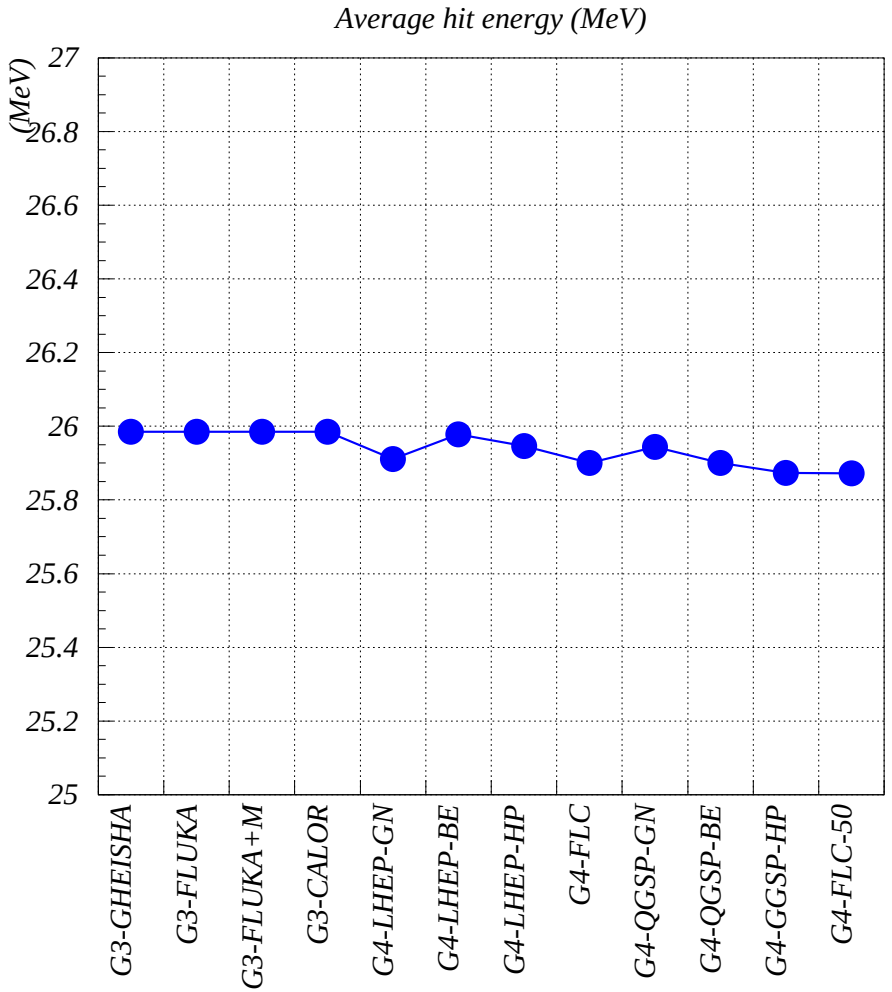


Average Hit Energy e 2 GeV

Average hit energy (MeV) in event for corrected energies



Average Hit Energy μ 2 GeV



Average Hit Energy e 2 GeV