ATLAS Pixel Test-Beam
(update)

Alberto Ribon
CERN/EP/SFT

Outline

- Motivations
- Setup
- Analysis
- Simulation
- Old results (2001, G4 4.0)
- New results
- Some checks
- Conclusions

Motivations

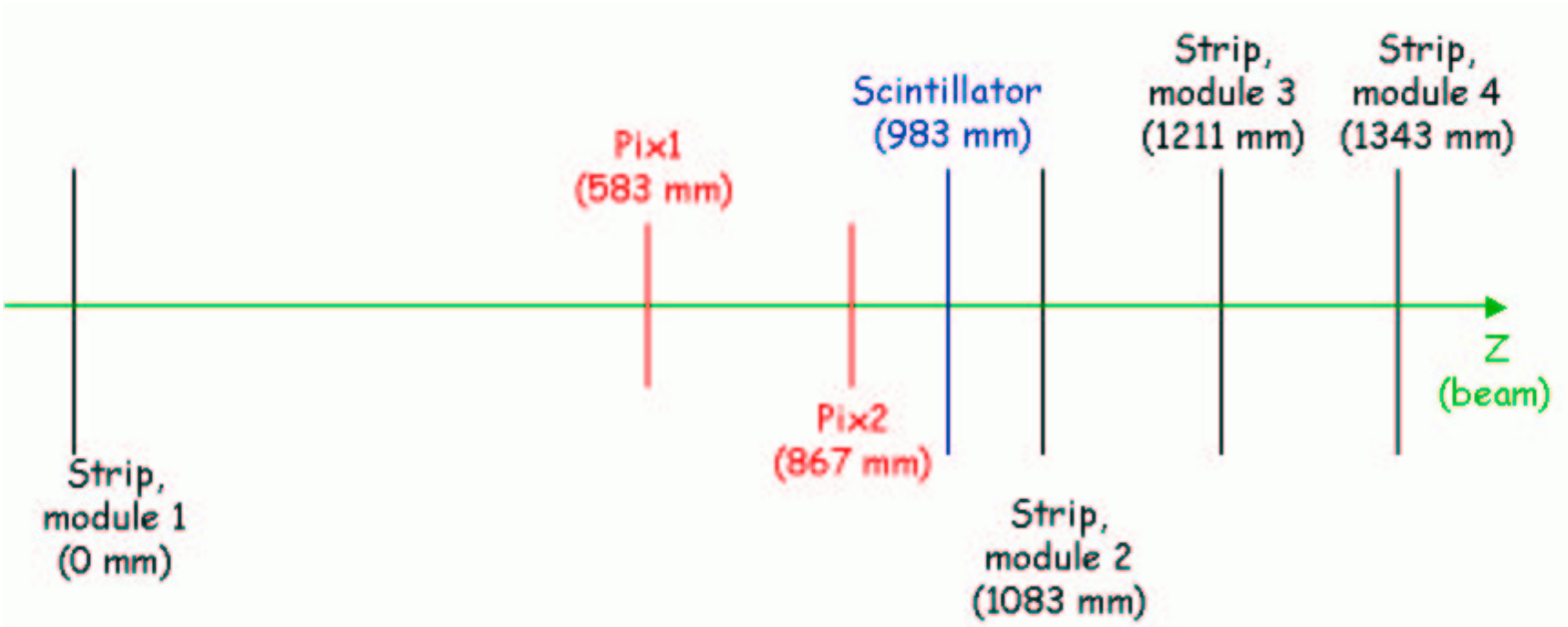
The august 2001 ATLAS Pixel Test-Beam offers an excellent opportunity to test in great detail the final state of hadronic interaction models (multiplicities, angular distributions, topologies).

Tracker test-beams provide a clean, simple and "microscopic" (single-interaction) data for the validation of hadronic physics simulations, that is complementary to the more typical and complex calorimeter test-beams, where the showers are the convolution of many effects (electromagnetic physics, multi-interactions, hadronic cross sections, hadronic final states).

This is an update of the analysis made two years ago by:
Dario Barberis, Mario Cervetto, Bianca Osculati (Genoa University, INFN).

Setup

- Beam: nominal 180 GeV π^+;
- Two pixels layers: $50\,\mu m\,X\,400\,\mu m$ thickness $280\,\mu m$;
- Telescope: 4 silicon microstrip planes, double-sided, $50\,\mu m$ pitch;
- Scintillator: trigger energy deposit ≥ 3 mips.



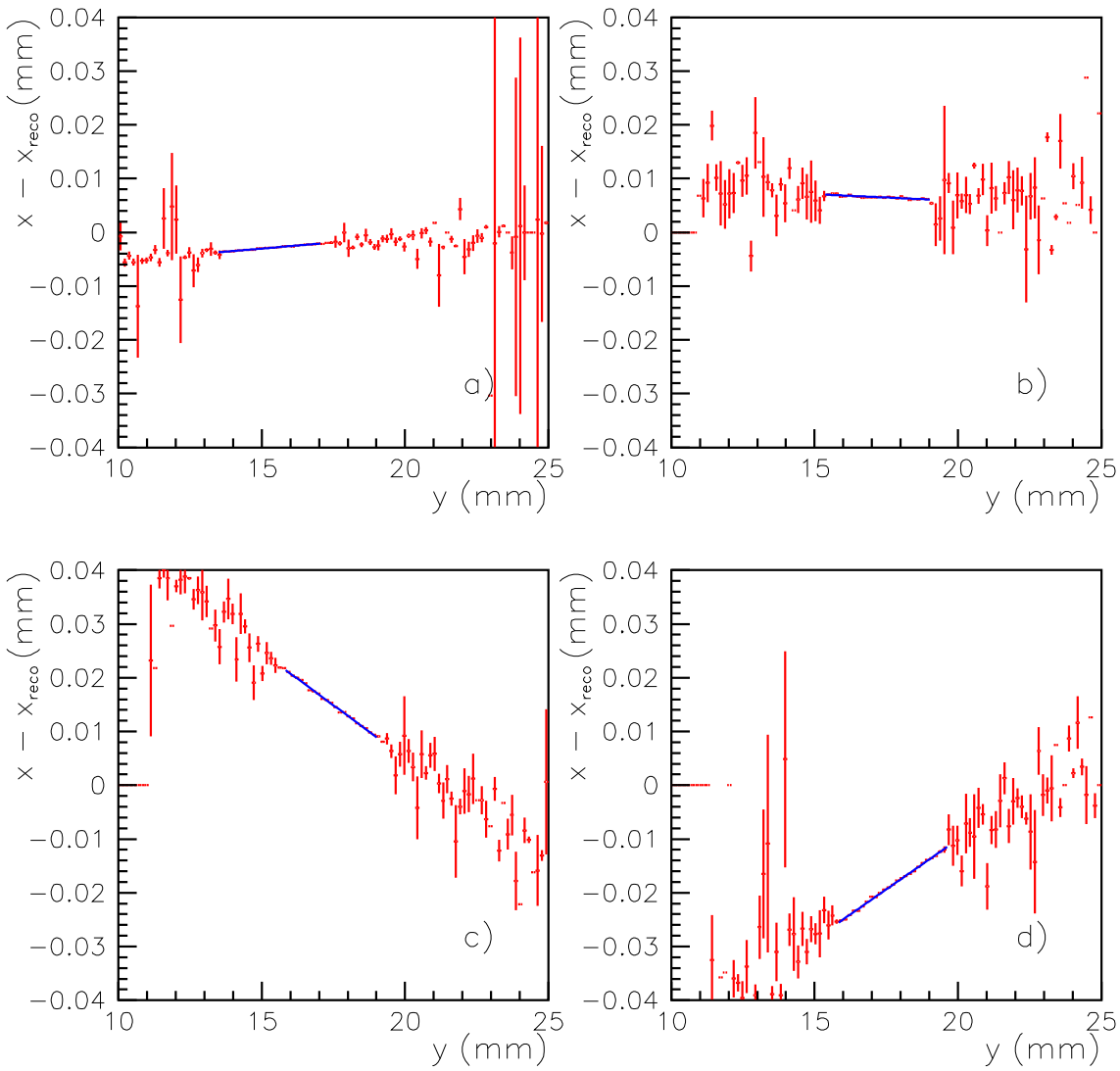
Analysis

- ≥ 3 clusters in each of the three microstrip planes downstream the pixels;
- alignment of the telescope planes;
- calibration of individual pixels (single pixel clusters, pulse injection, radioactive sources);
- track reconstruction in the three microstrip planes downstream of the pixels (straight line fit in xz and yz planes, match in energy);
- interaction point (vertex) reconstruction (weighted mean of all two-by-two track intersections); Pix2 is selected because of the better resolution;
- selection of the interactions in the silicon sensor (closest pixel cluster in transverse plane, $\Delta z < 4\,mm$; $E_{loss}/N_{dig} > 100,000$ electrons).

Then, study of pixel cluster corresponding to the reconstructed vertex coordinate.

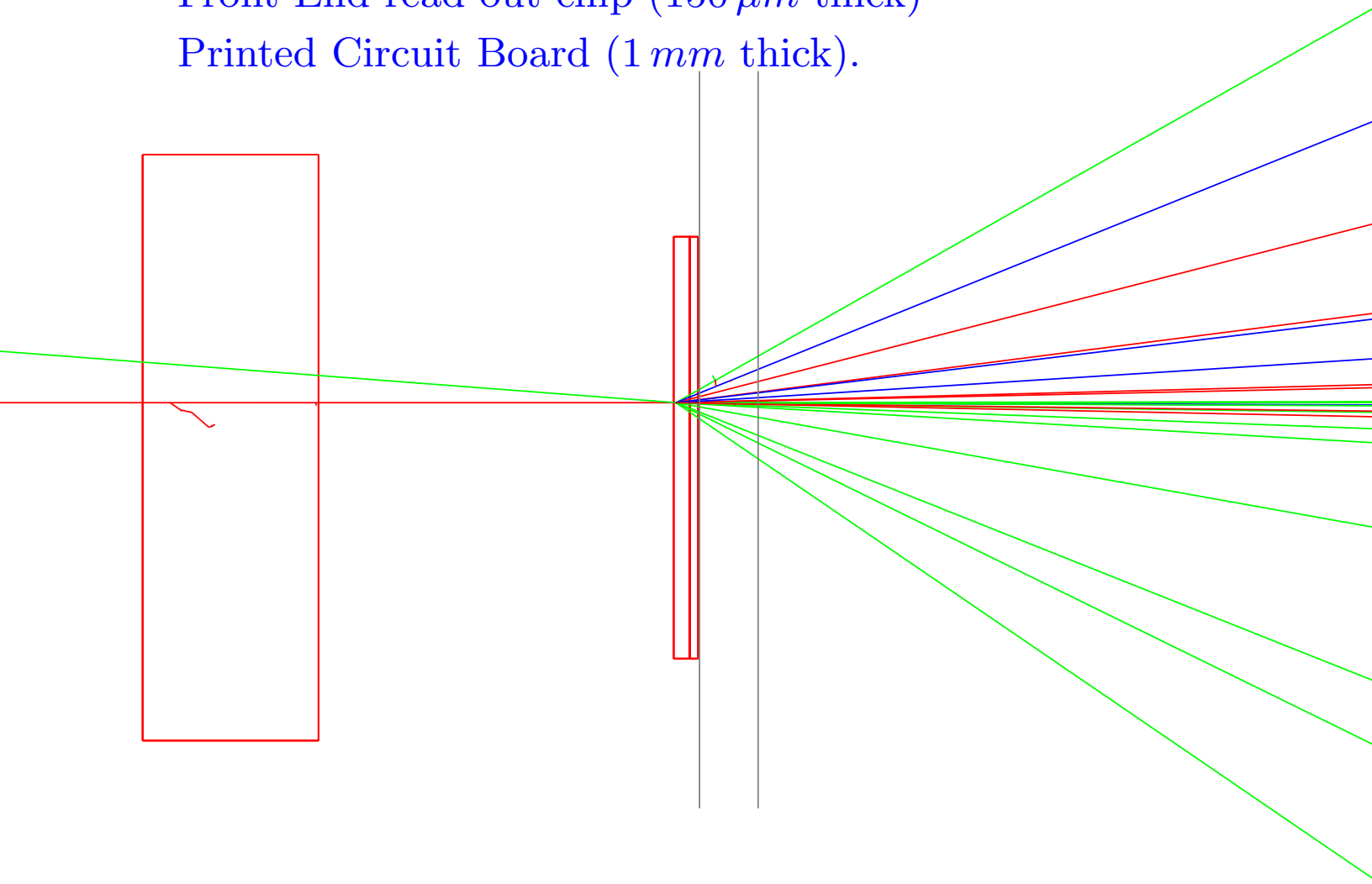
Alignement of the Telescope

Small and different rotation angle in each strip plane.



Pixel Detector

Plastic cover ($3\,mm$ thick)
Silicon sensor ($280\,\mu m$ thick)
Front End read-out chip ($150\,\mu m$ thick)
Printed Circuit Board ($1\,mm$ thick).



Geant4 Simulation

- Geant4 5.2
- Linux RH 7.3, gcc 2.95.2
- CLHEP 1.8.0.0
- Physics lists: LHEP 3.3, QGSP 2.3, QGSP_BIC 0.5, QGSC 2.4, FTFP 2.3
- Beam composition: 67 % p, 29 % π^+, 4 % K^+
- Beam divergence, "noise", cross-talk
- Pix1 removed to speed up
- $E_{loss}/N_{dig} > 56,000$ electrons (different from real data maybe because of non-linearities in the calibration curve)
- 10 million events generated for each Physics List; in about 0.9 % of them there is an hadronic interaction in Pix2.

Cross section breakdown

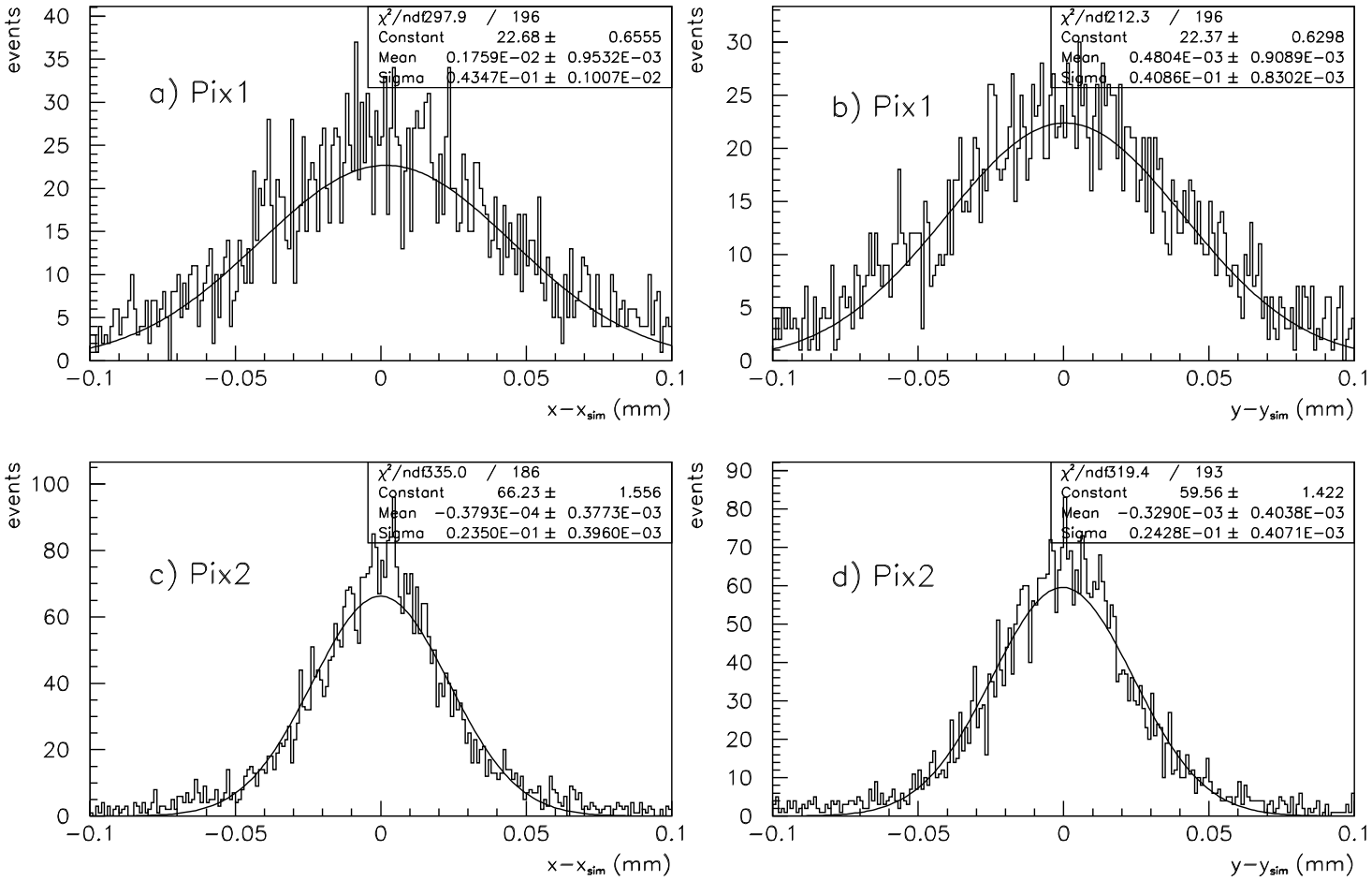
Fraction of the beam particles that have interacted in Pix2 (including the plastic cover):

Physics list	p	π^+	K^+
LHEP	0.99 %	0.73 %	0.64 %
QGSx	0.99 %	0.66 %	0.64 %

Notice that the QGSx physics lists include the new pion cross sections, whereas LHEP uses the default ones.

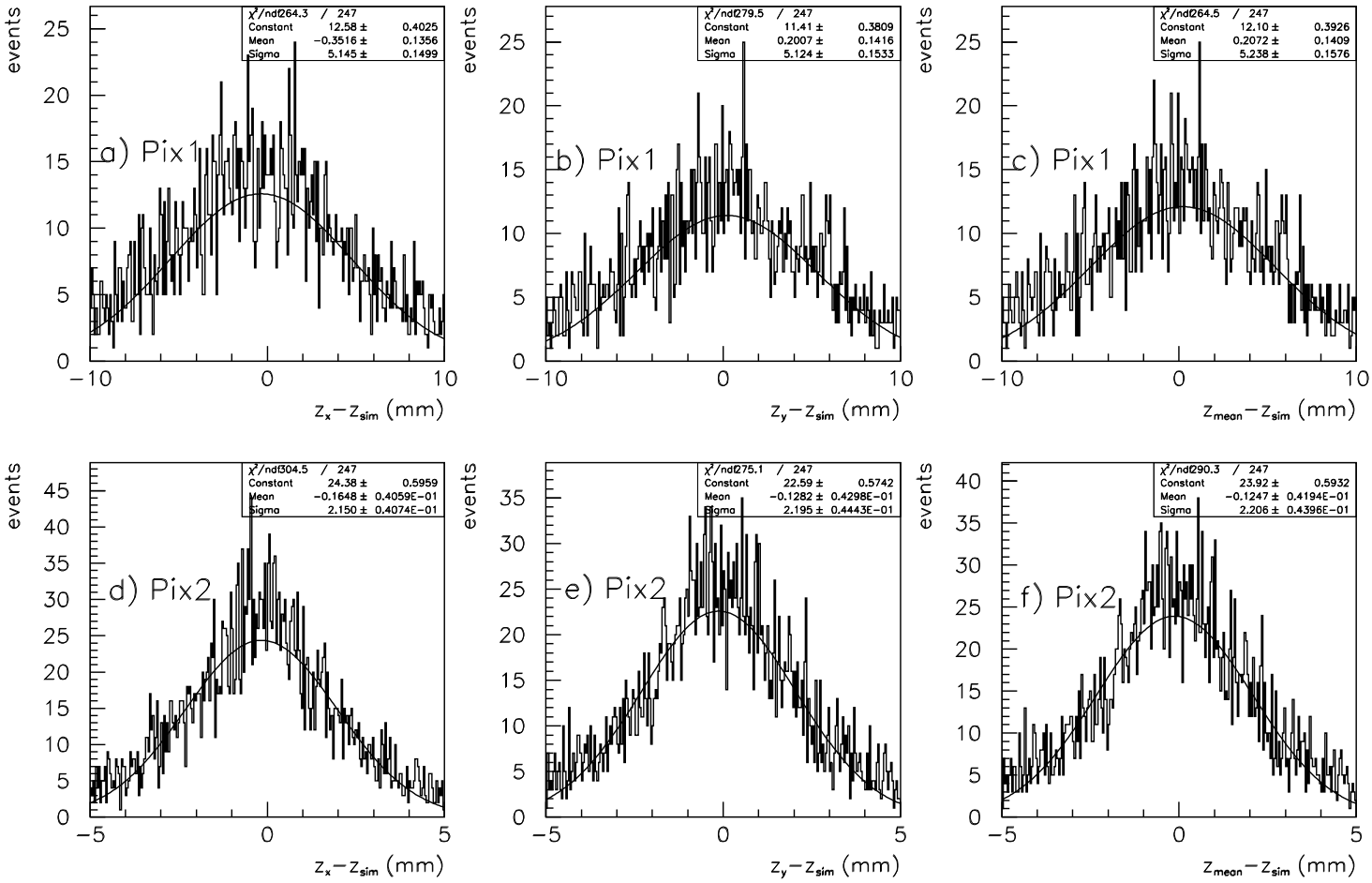
Transverse Vertex Resolution

x y



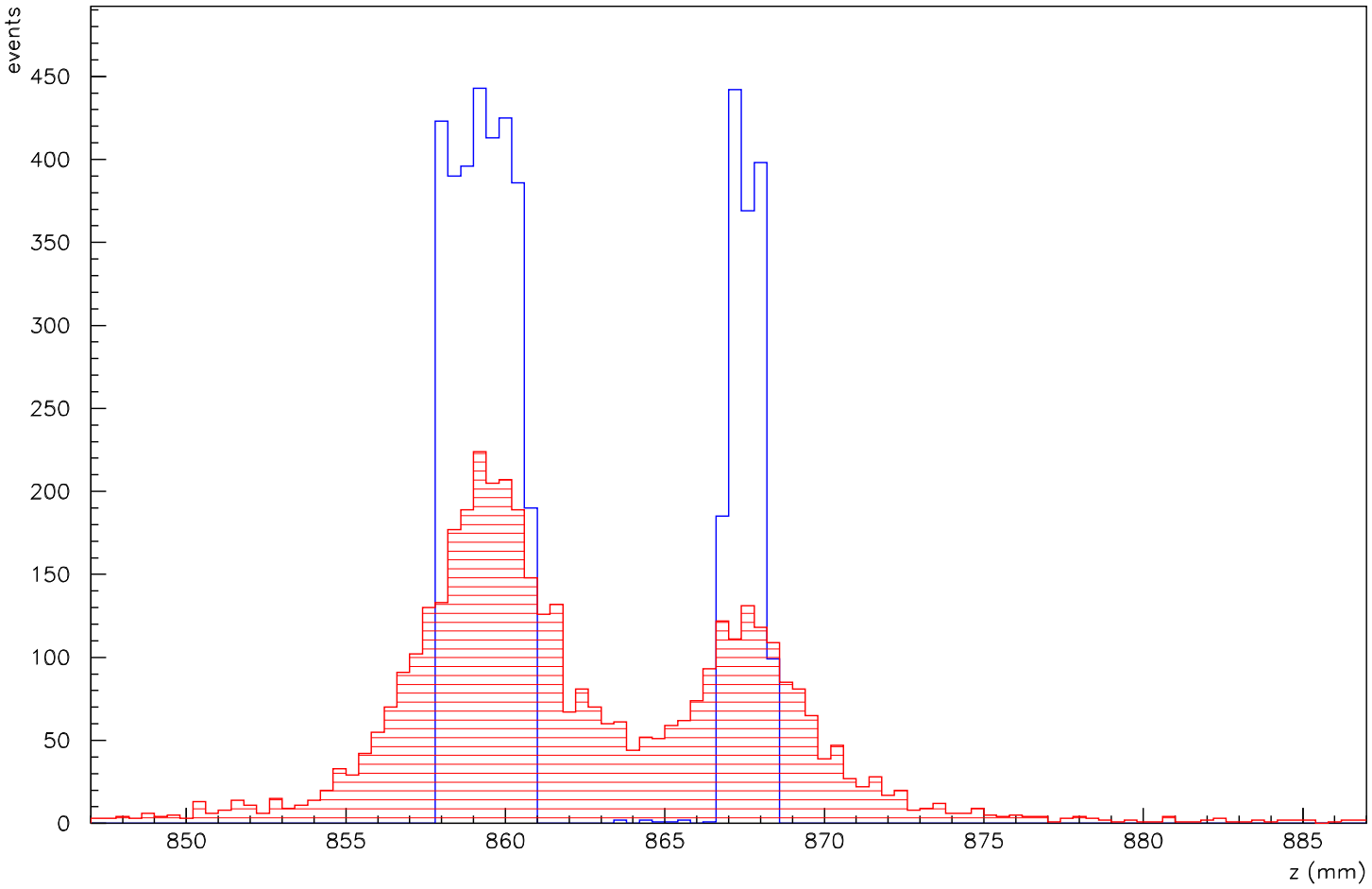
Longitudinal Vertex Resolution

xz yz z_{mean}



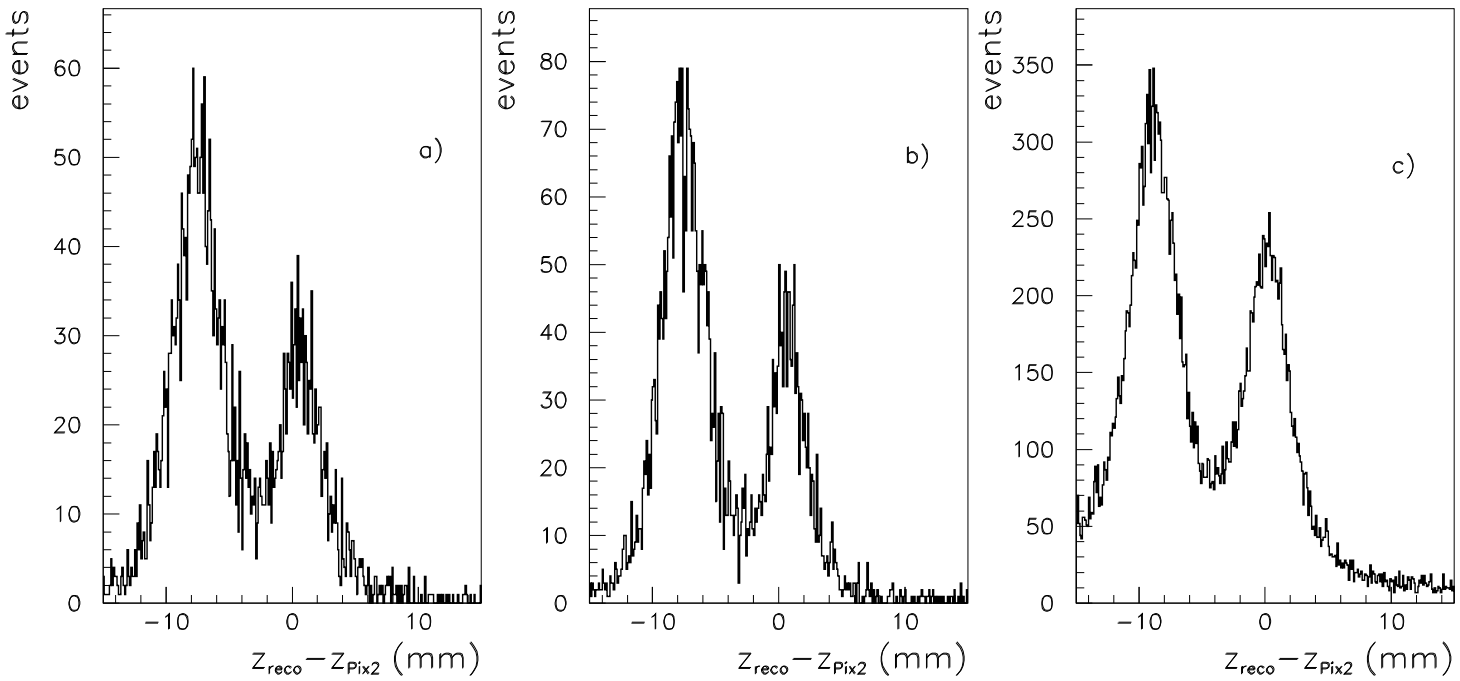
Vertex z coordinate

Simulated (true) and reconstructed
z vertex coordinate in the Pix2 region.



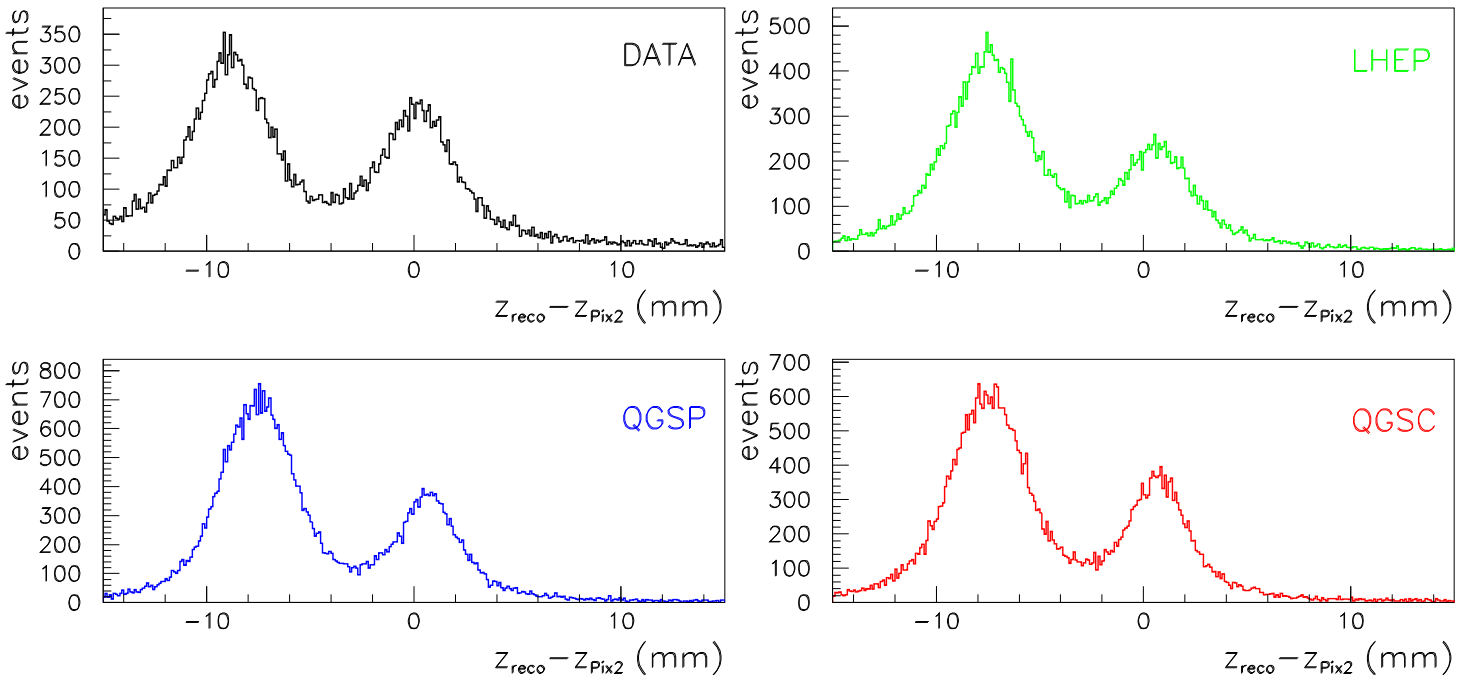
Old

z distance between the reconstructed vertices and the z position of the center of the sensor.

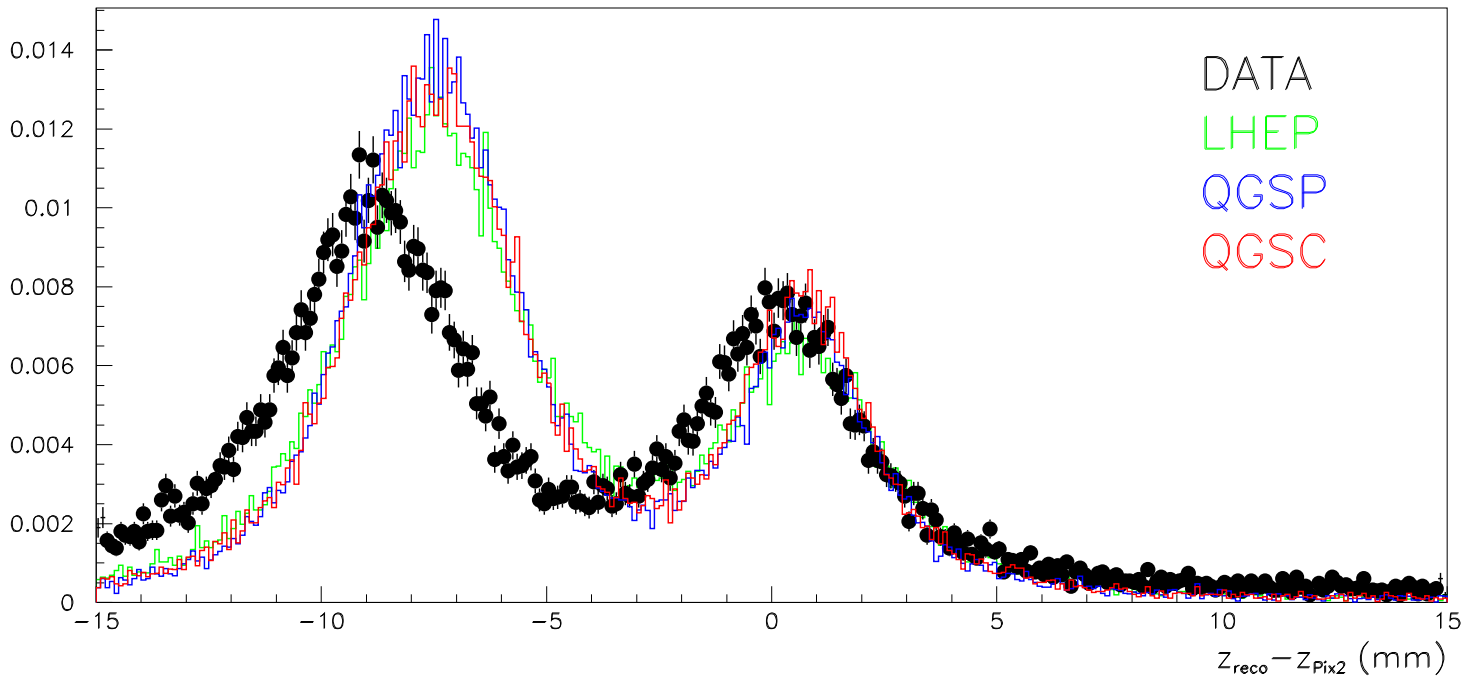


a) Param b) Theory c) Data

New

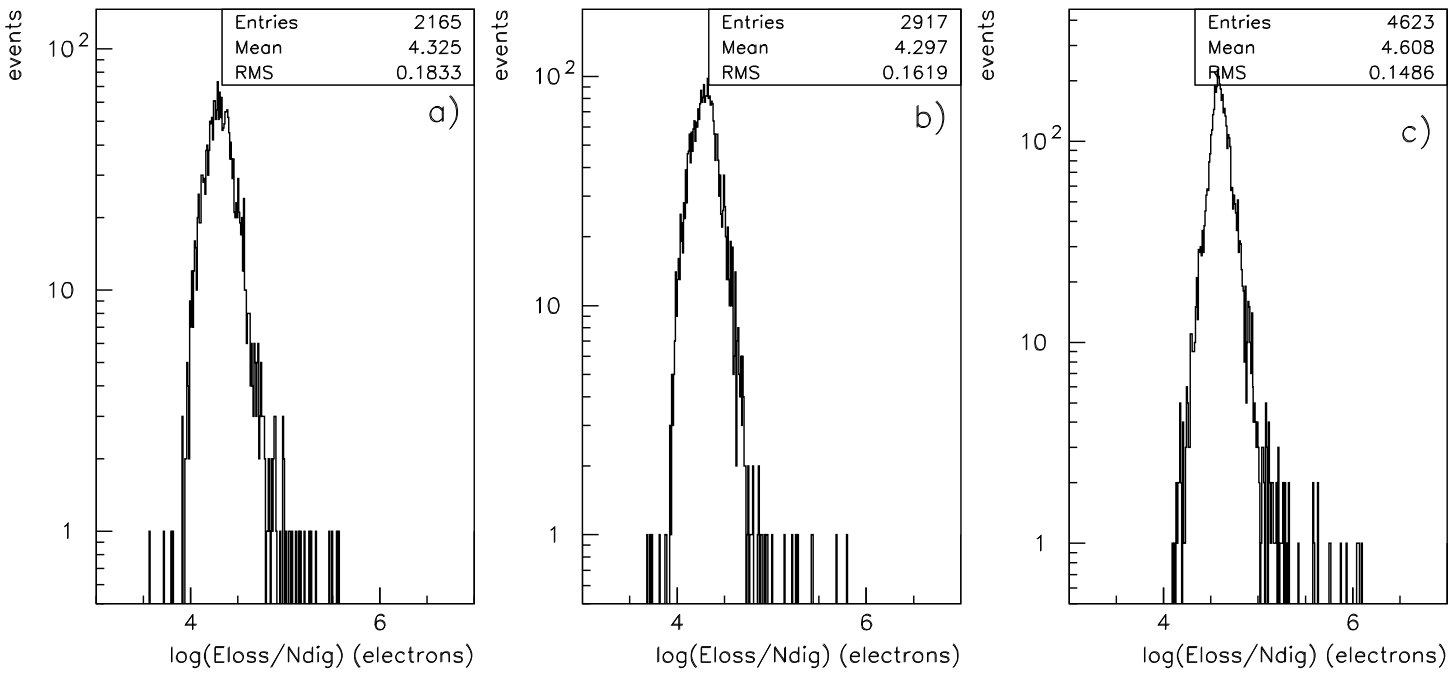


New


DATA
LHEP
QGSP
QGSC
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
−15
−10
−5
0
5
10
15
$z_{reco} - z_{Pix2}$ (mm)

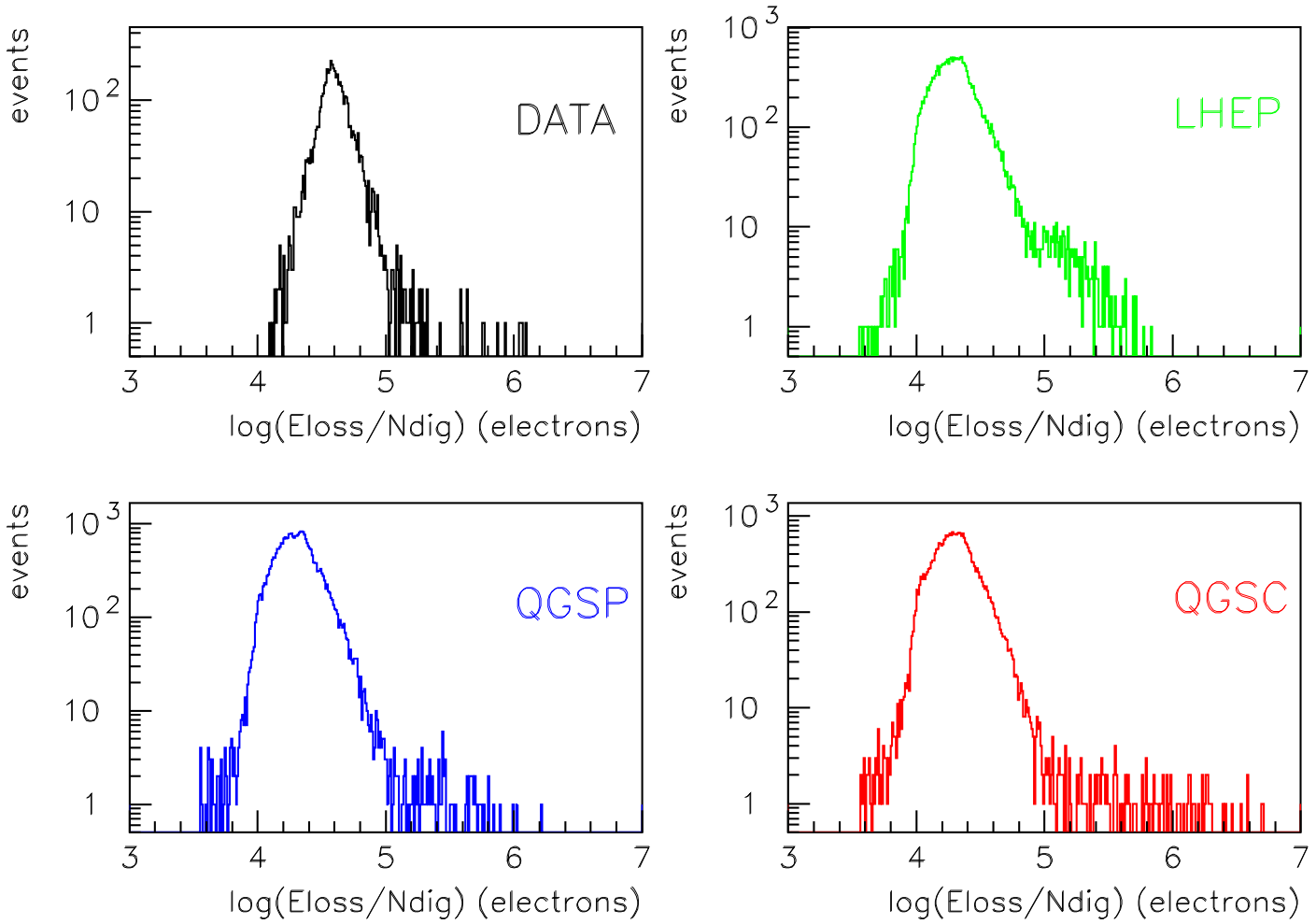
Old

Normalised energy loss for events with interaction vertices reconstructed in the plastic cover, far enough from the sensor to be resolved by our z resolution.

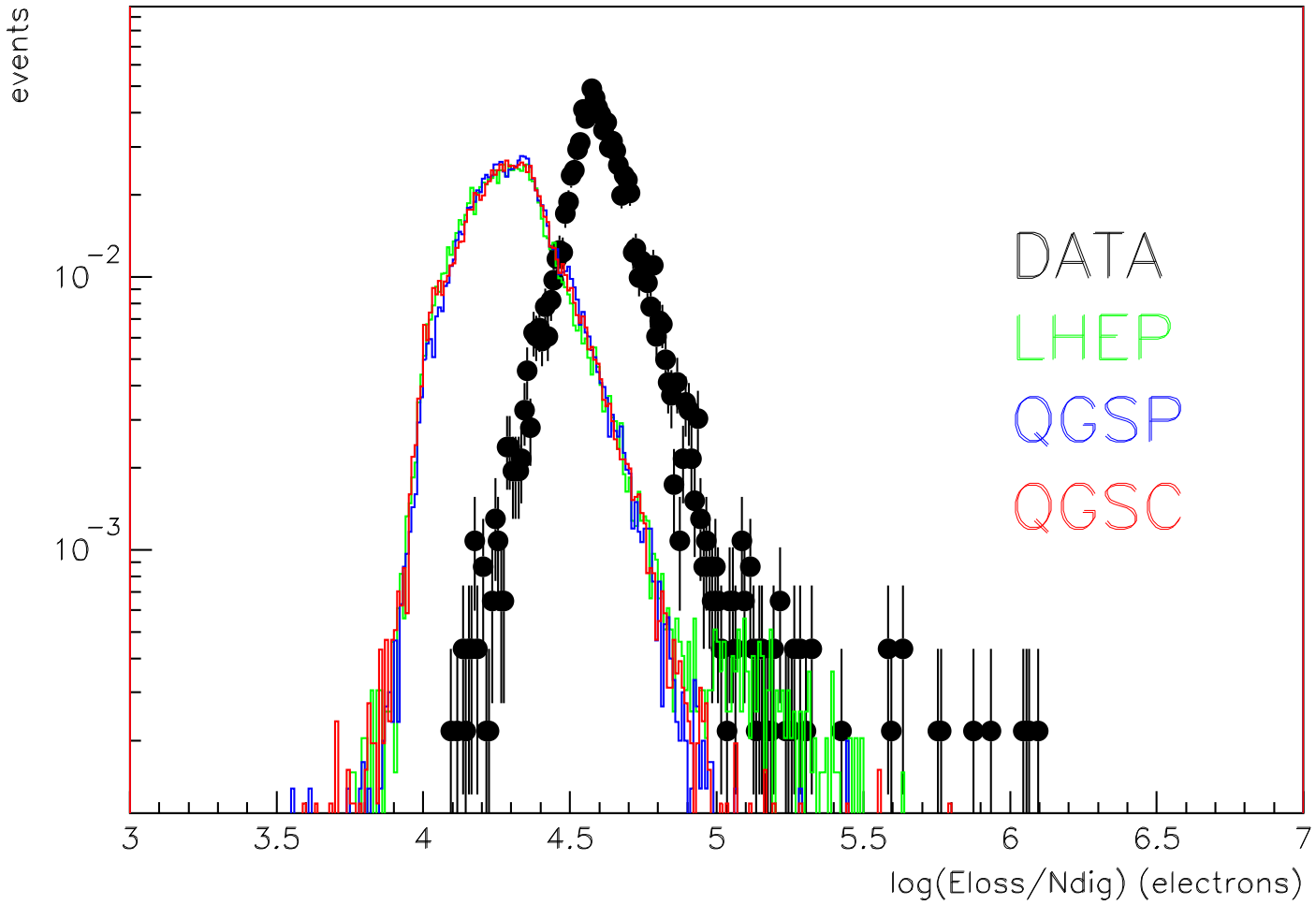


a) Param b) Theory c) Data

New

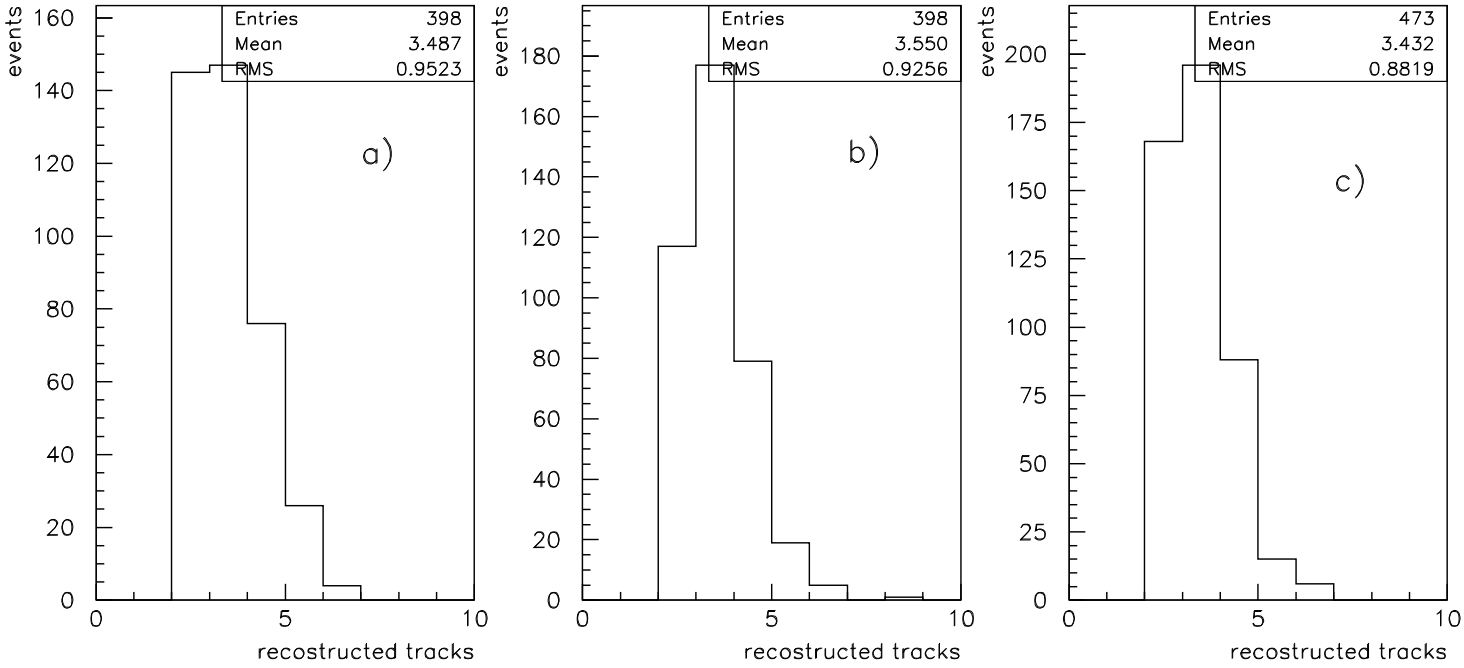


New


events
10^{-2}
10^{-3}
3
3.5
4
4.5
5
5.5
6
6.5
7
log(Eloss/Ndig) (electrons)
DATA
LHEP
QGSP
QGSC

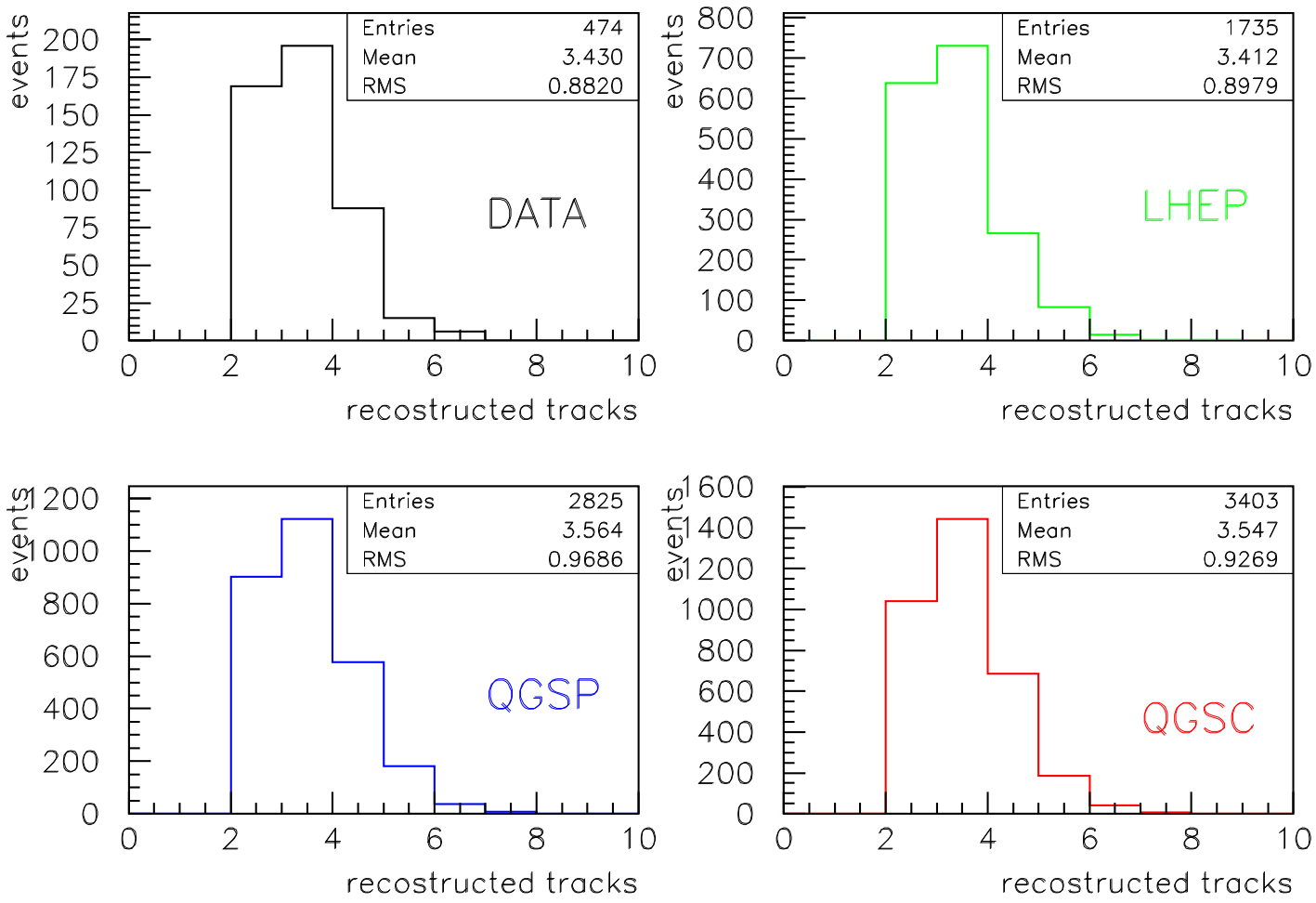
Old

Number of reconstructed tracks in the interaction.

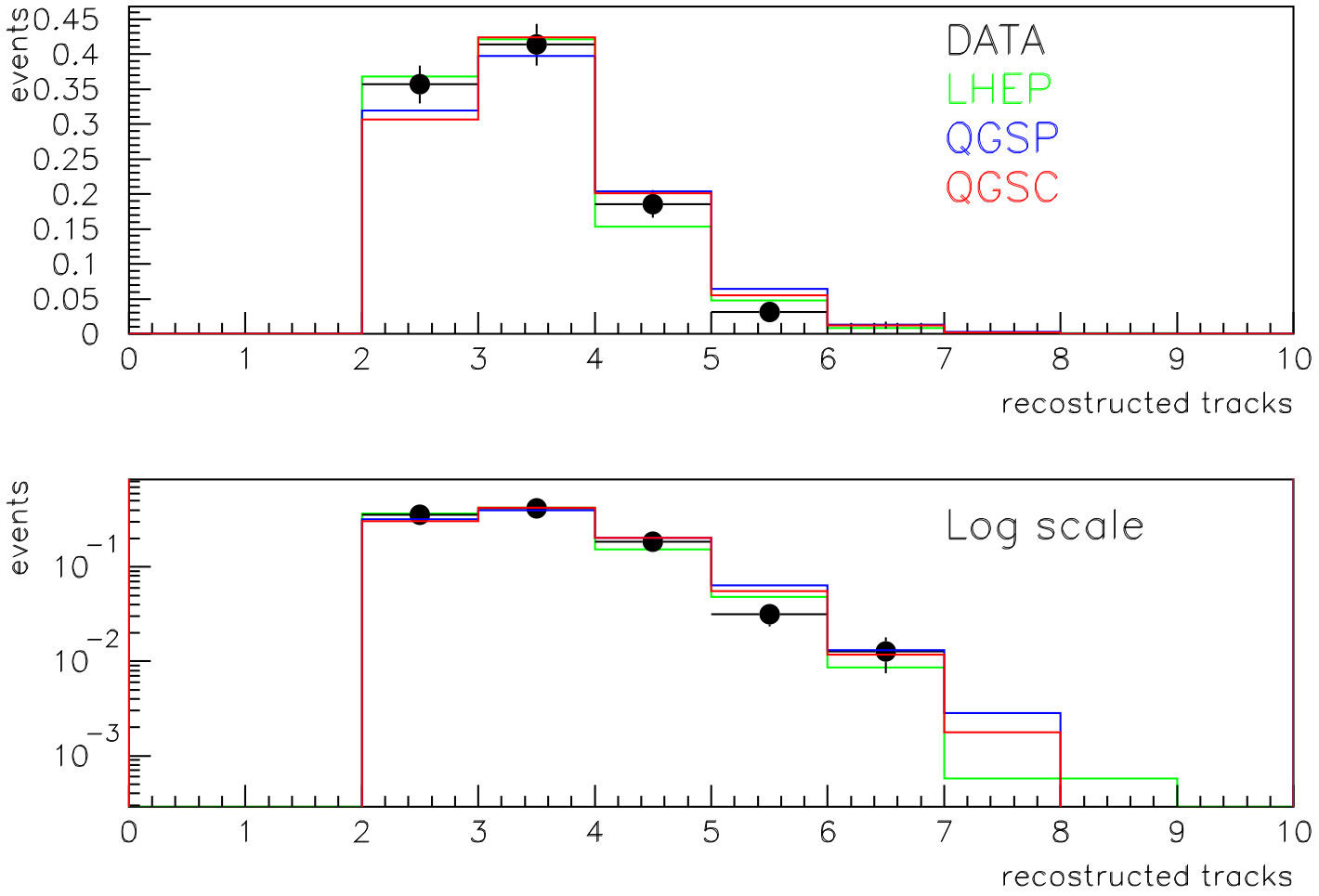


a) Param b) Theory c) Data

New

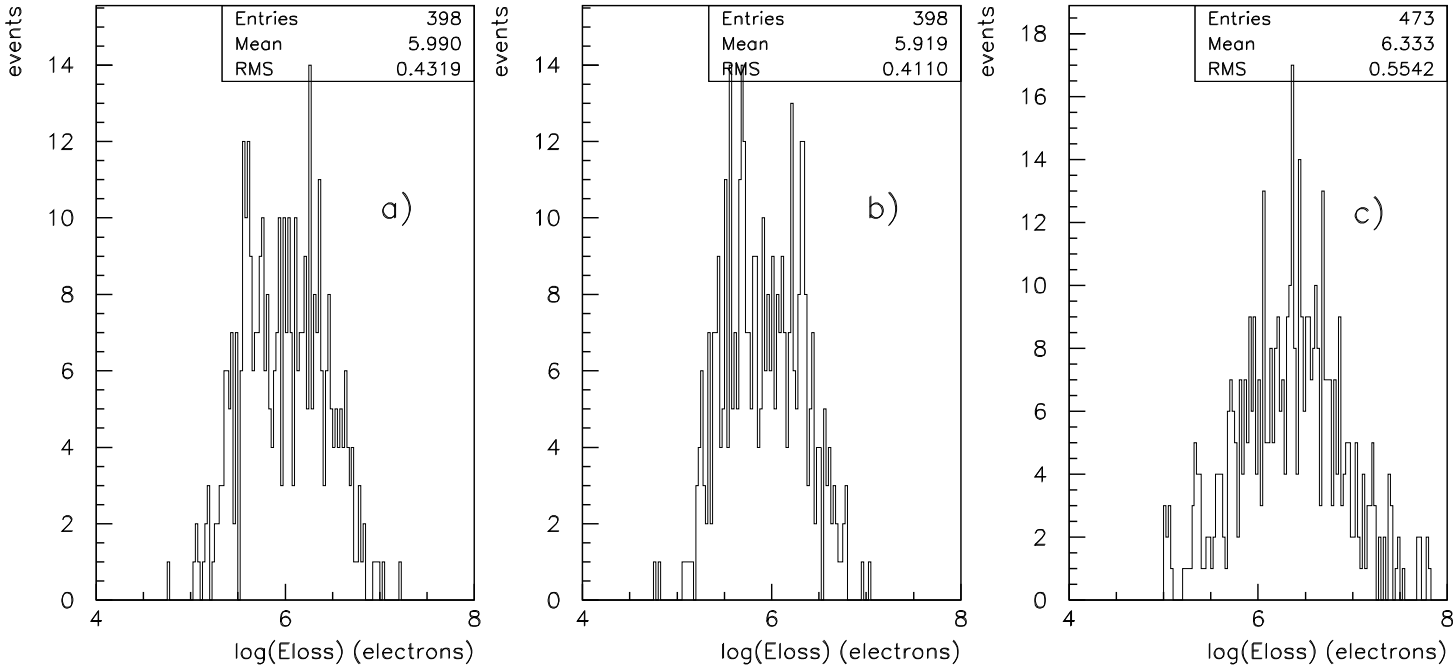

events
Entries 474
Mean 3.430
RMS 0.8820
DATA
recostructed tracks
events
Entries 1735
Mean 3.412
RMS 0.8979
LHEP
recostructed tracks
events
Entries 2825
Mean 3.564
RMS 0.9686
QGSP
recostructed tracks
events
Entries 3403
Mean 3.547
RMS 0.9269
QGSC
recostructed tracks

New


events
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
DATA
LHEP
QGSP
QGSC
0 1 2 3 4 5 6 7 8 9 10
recostructed tracks
events
10^{-1}
10^{-2}
10^{-3}
Log scale
0 1 2 3 4 5 6 7 8 9 10
recostructed tracks

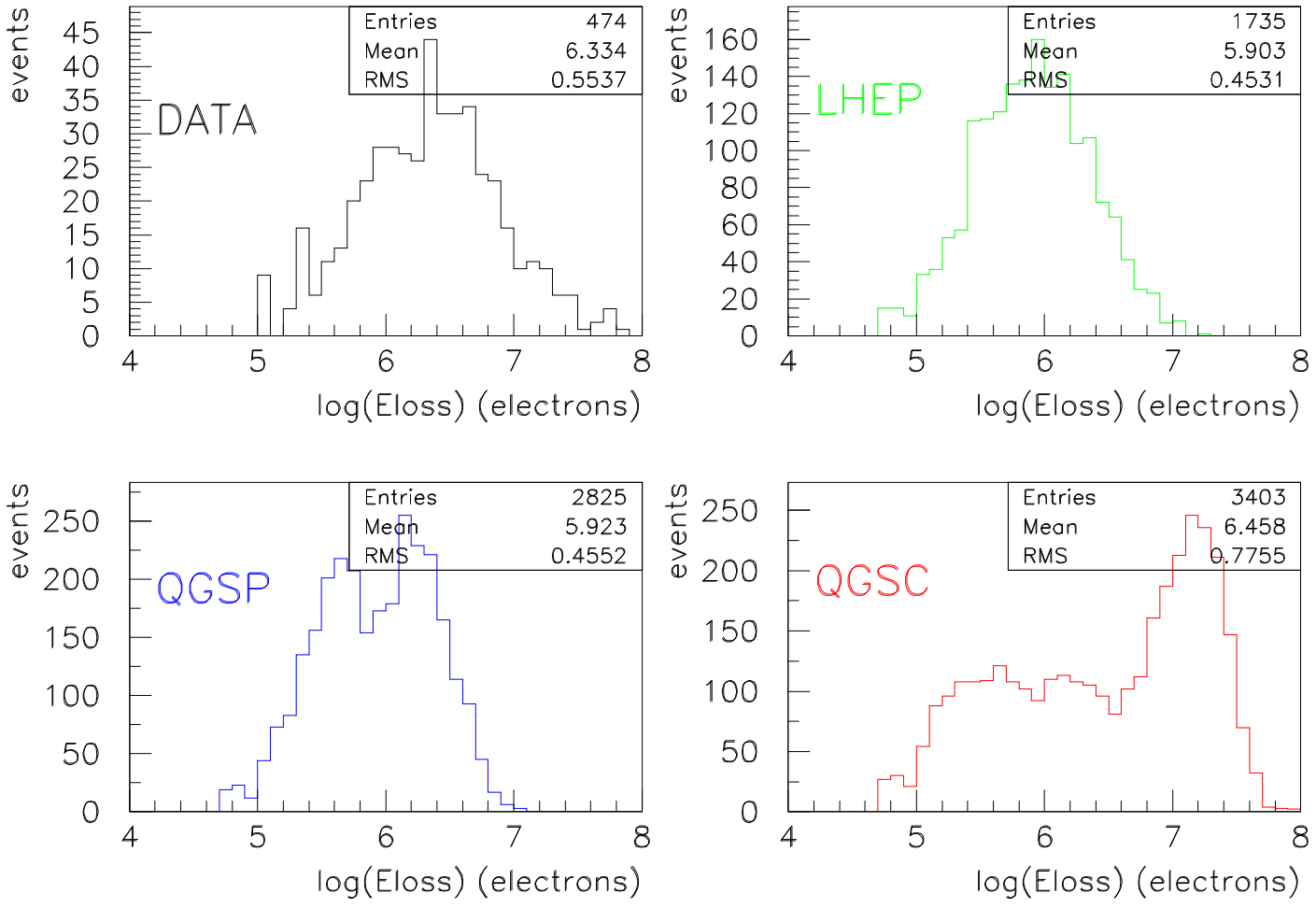
Old

Log of the total energy released in the cluster.

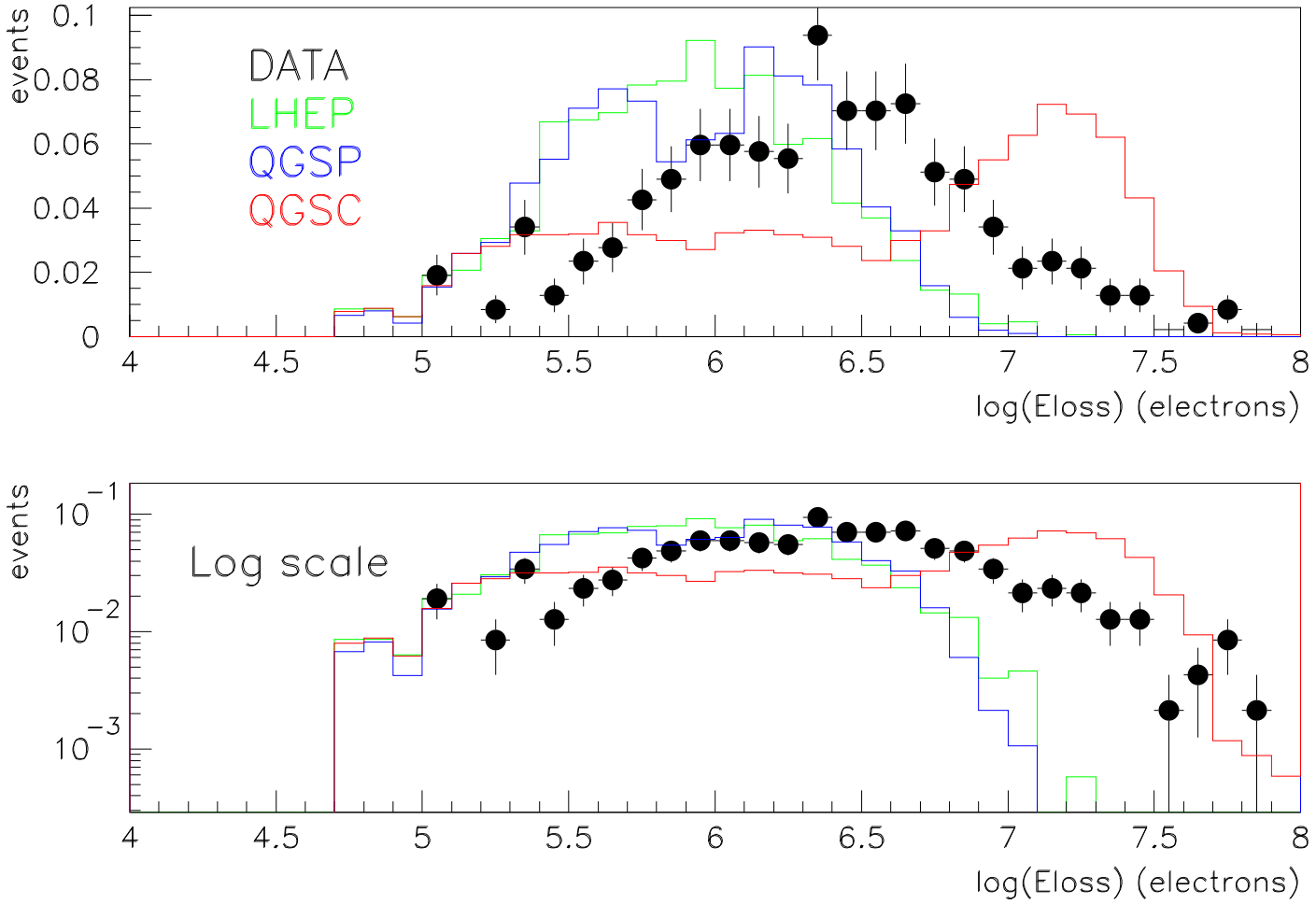


a) Param b) Theory c) Data

New

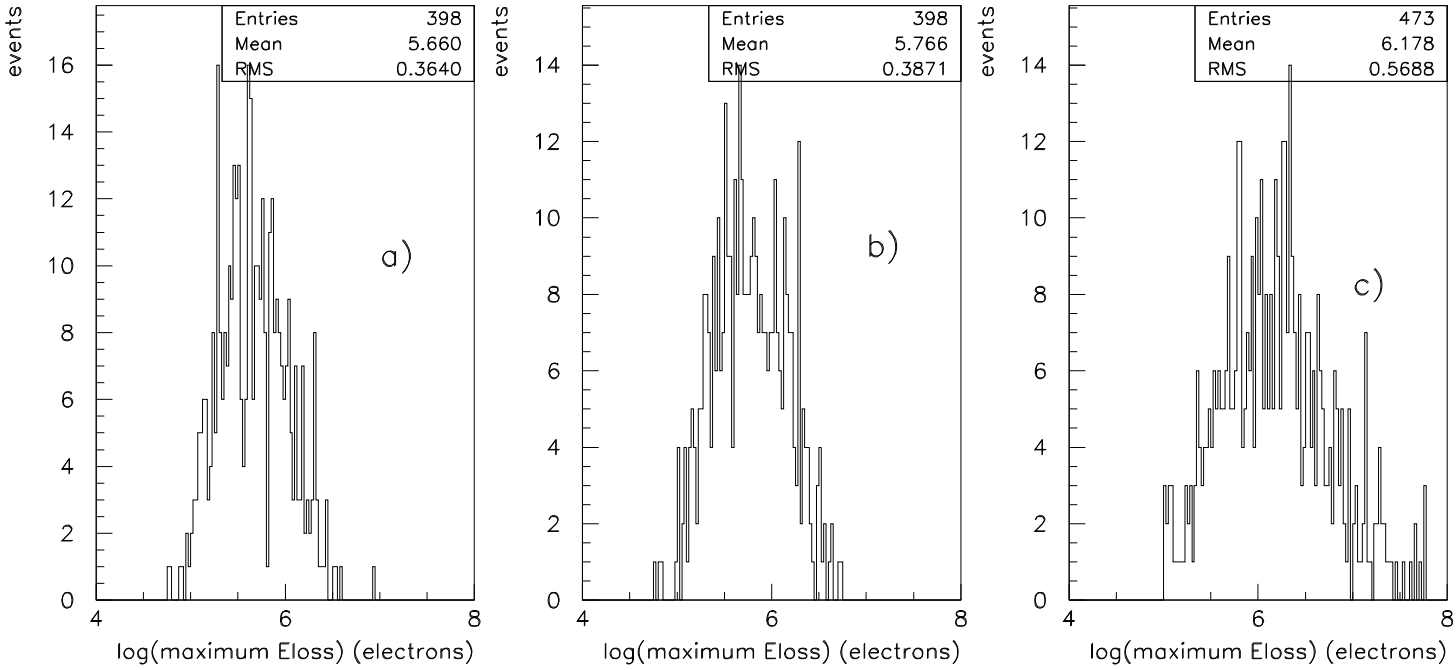

DATA
Entries 474
Mean 6.334
RMS 0.5537
LHEP
Entries 1735
Mean 5.903
RMS 0.4531
QGSP
Entries 2825
Mean 5.923
RMS 0.4552
QGSC
Entries 3403
Mean 6.458
RMS 0.7755
events
log(Eloss) (electrons)

New


events
0.1
0.08
0.06
0.04
0.02
0
DATA
LHEP
QGSP
QGSC
4
4.5
5
5.5
6
6.5
7
7.5
8
log(Eloss) (electrons)
events
10^{-1}
10^{-2}
10^{-3}
Log scale
4
4.5
5
5.5
6
6.5
7
7.5
8
log(Eloss) (electrons)

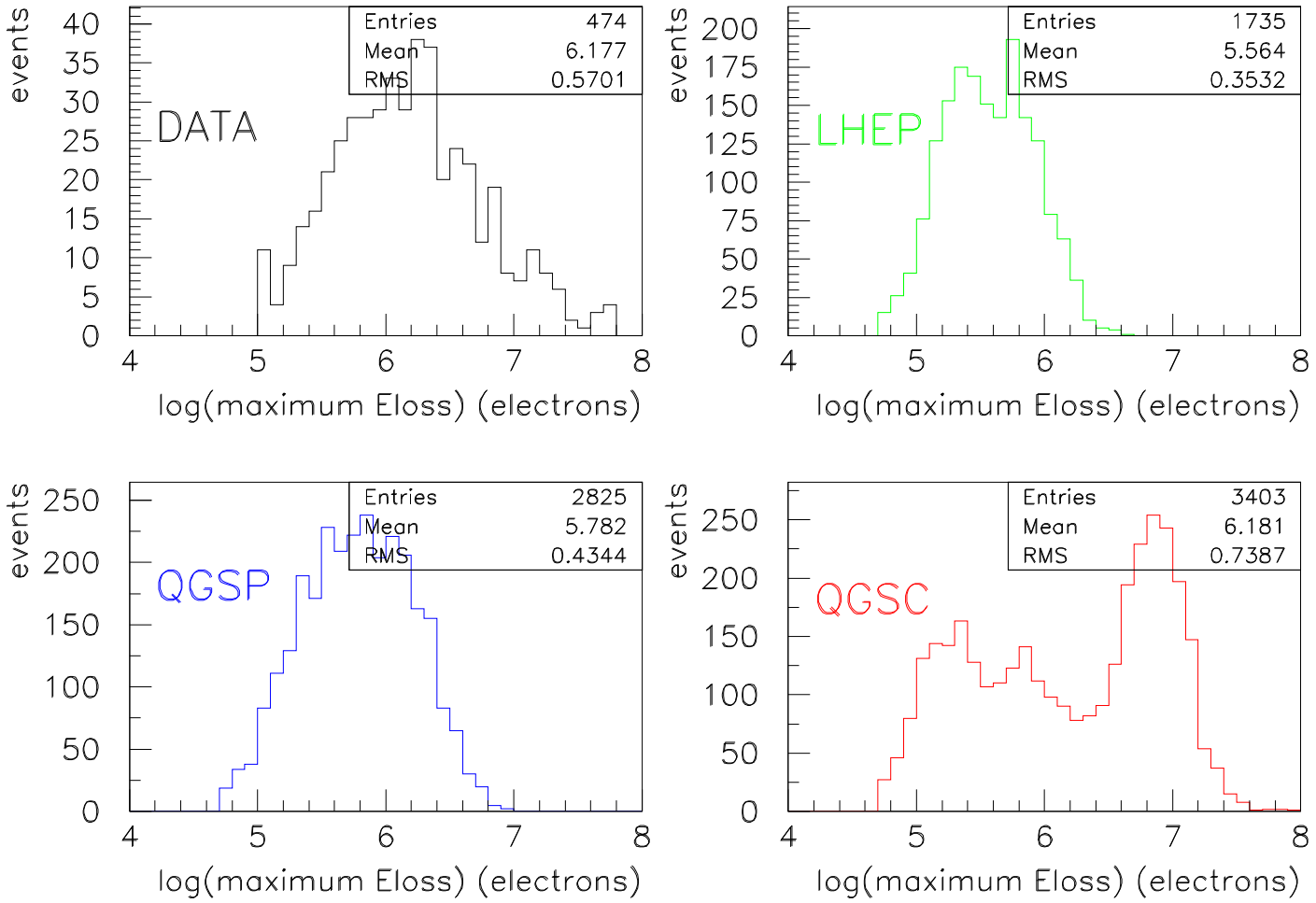
Old

Log of the maximum energy released in a pixel.

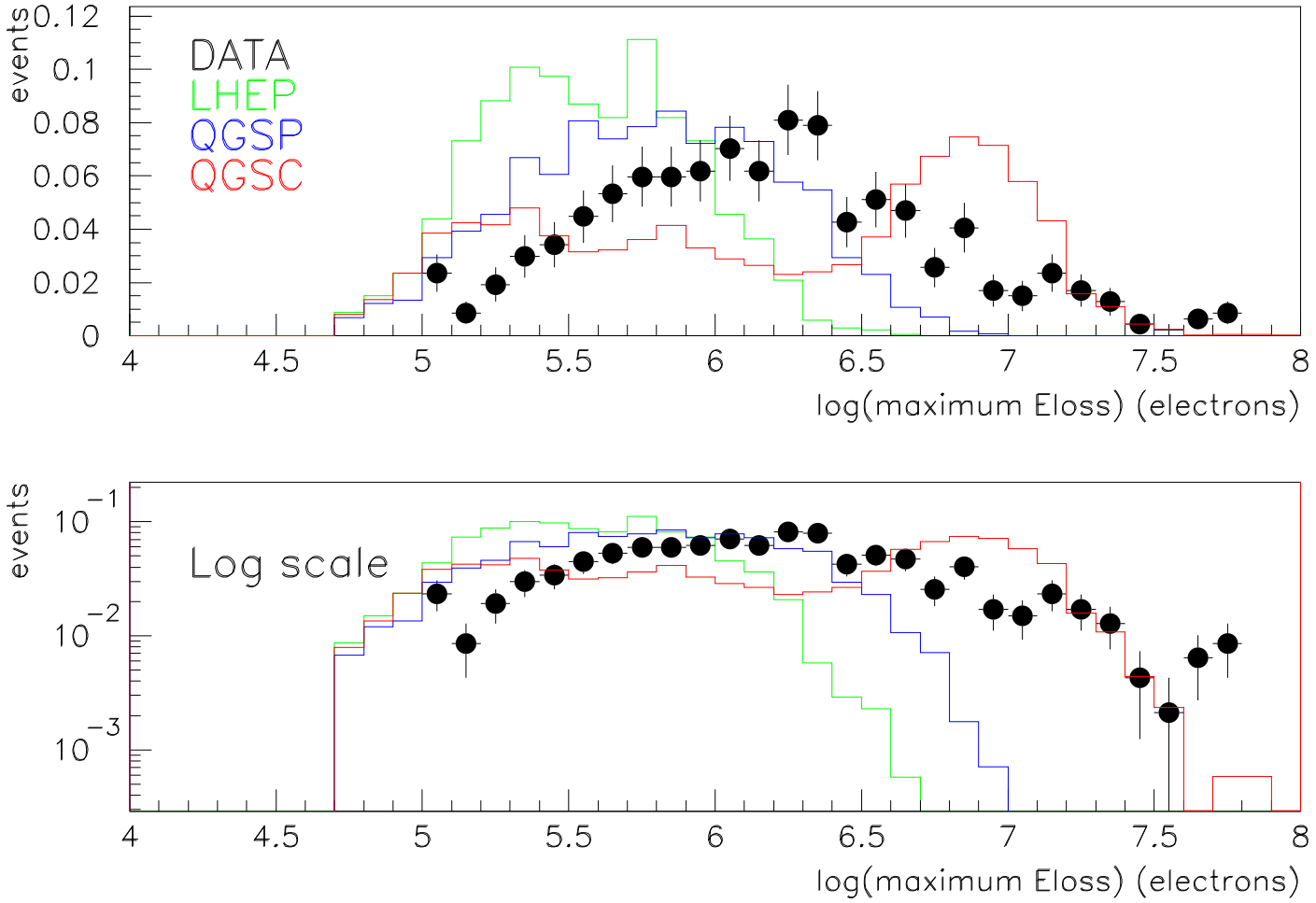


a) Param b) Theory c) Data

New

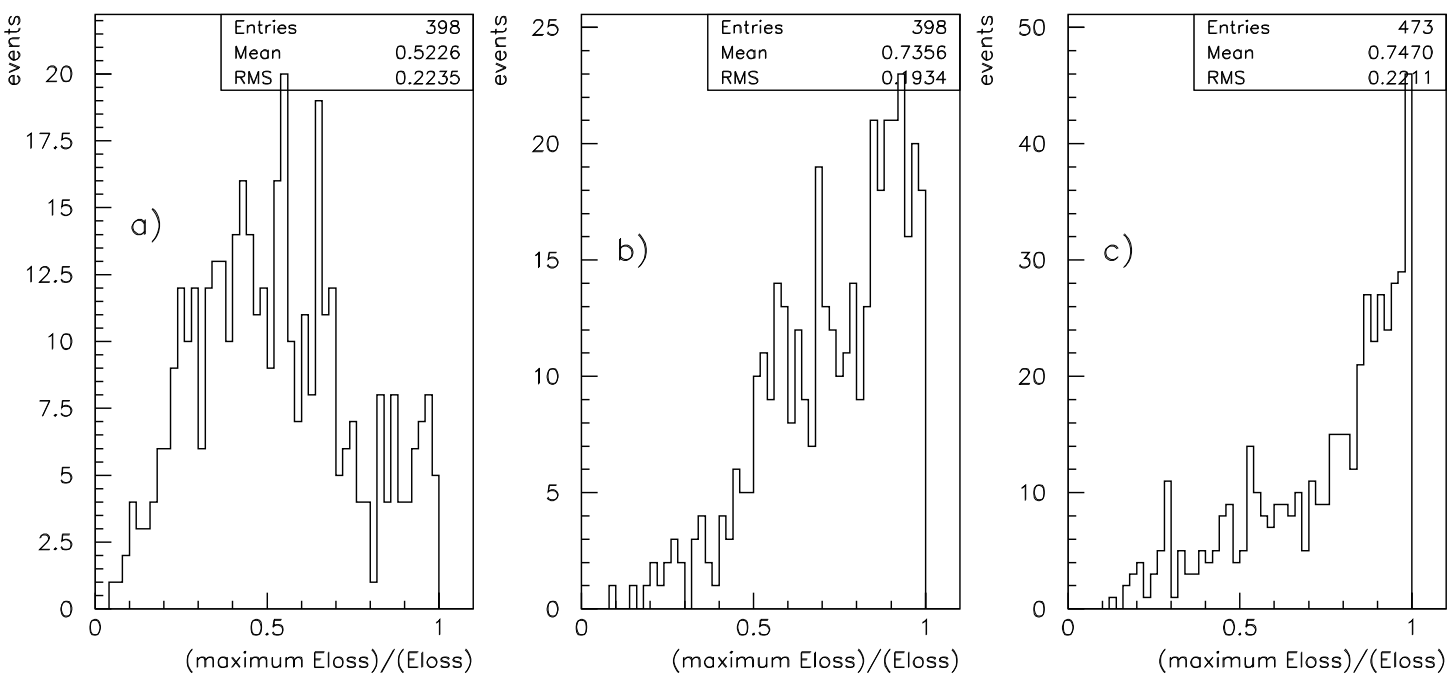

DATA
Entries 474
Mean 6.177
RMS 0.5701
LHEP
Entries 1735
Mean 5.564
RMS 0.3532
QGSP
Entries 2825
Mean 5.782
RMS 0.4344
QGSC
Entries 3403
Mean 6.181
RMS 0.7387
events
log(maximum Eloss) (electrons)

New


events
0.12
0.1
0.08
0.06
0.04
0.02
0
DATA
LHEP
QGSP
QGSC
4
4.5
5
5.5
6
6.5
7
7.5
8
log(maximum Eloss) (electrons)
events
10^{-1}
10^{-2}
10^{-3}
Log scale
4
4.5
5
5.5
6
6.5
7
7.5
8
log(maximum Eloss) (electrons)

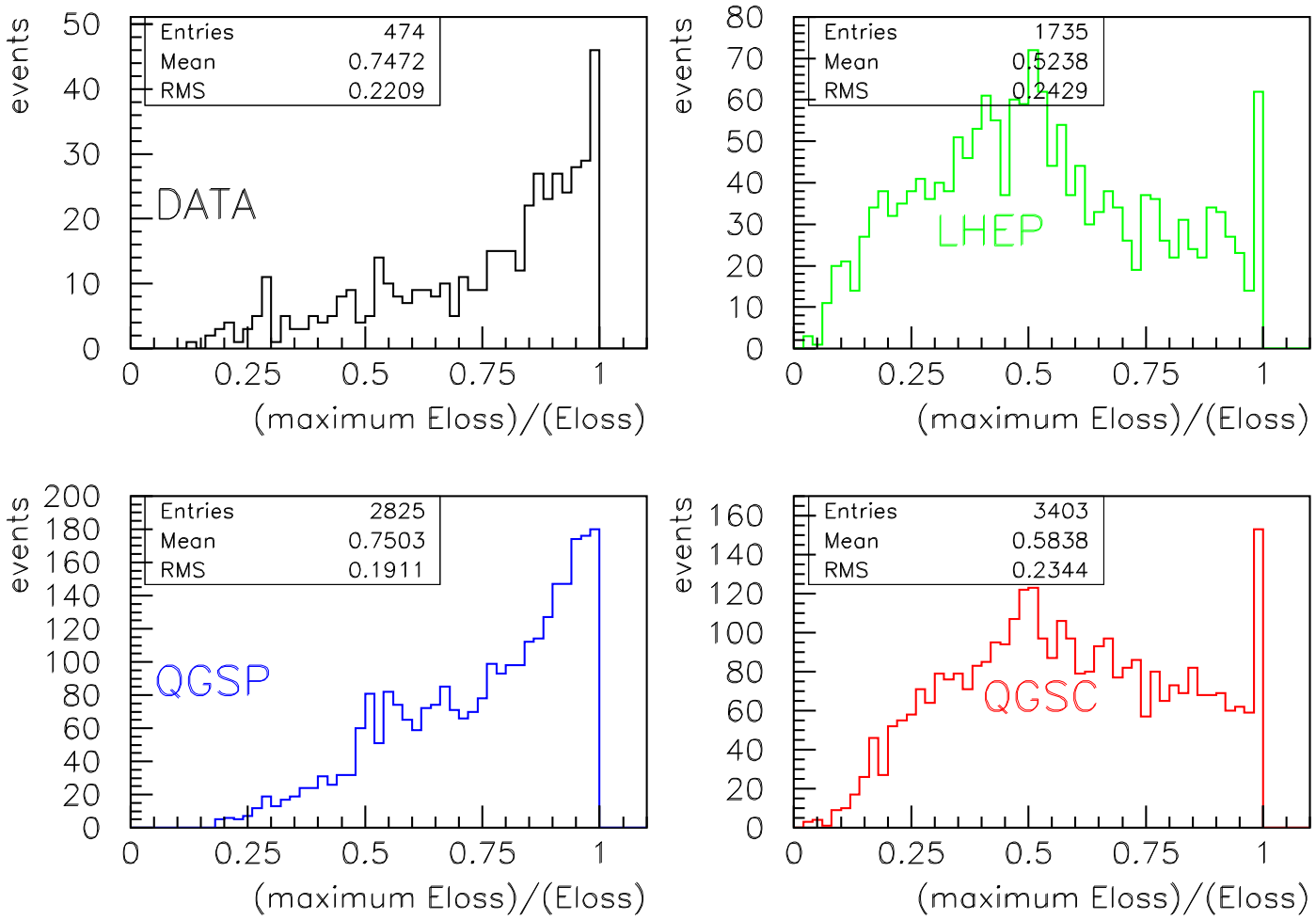
Old

Ratio of the maximum energy released in a pixel and the total cluster energy.

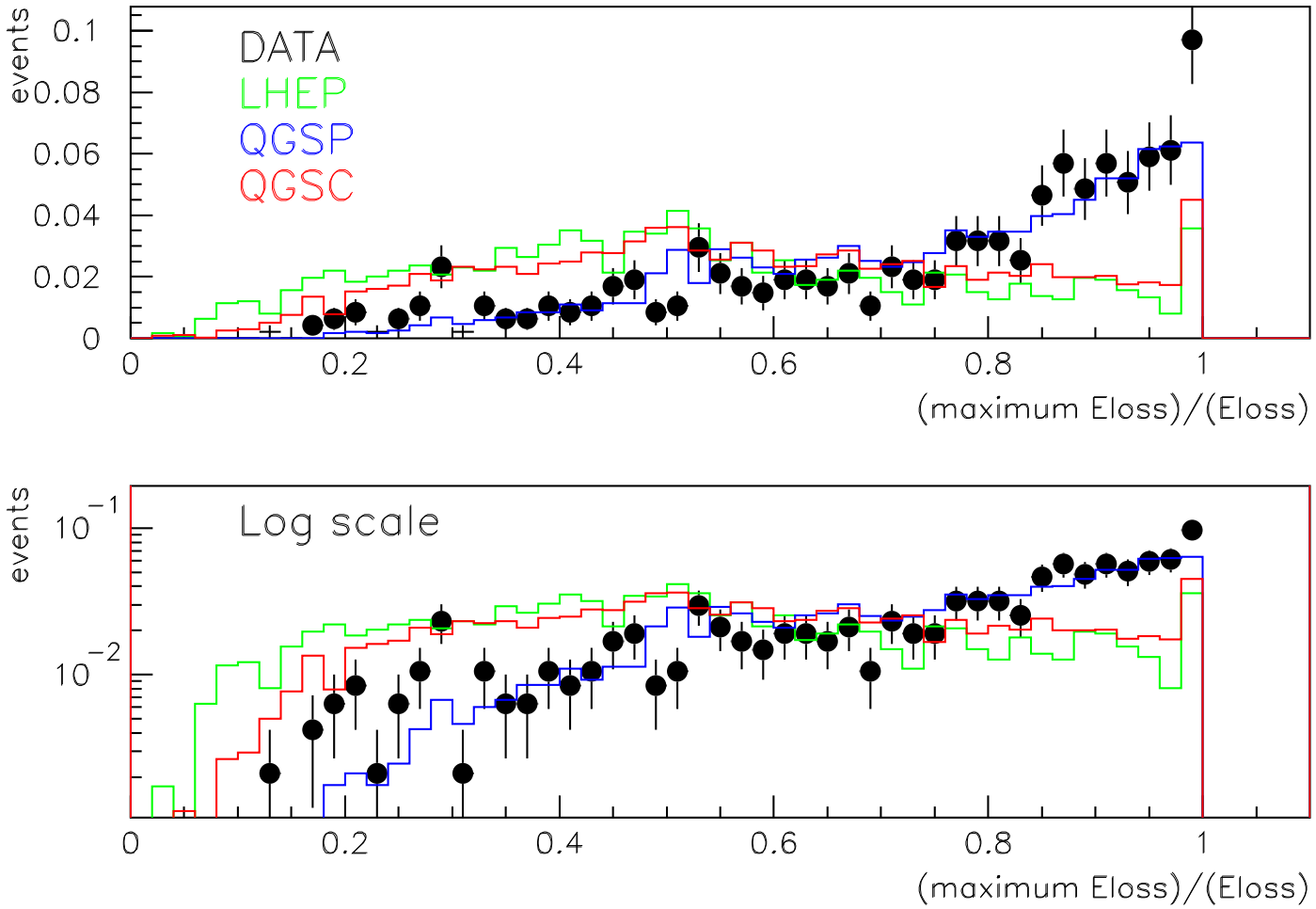


a) Param b) Theory c) Data

New

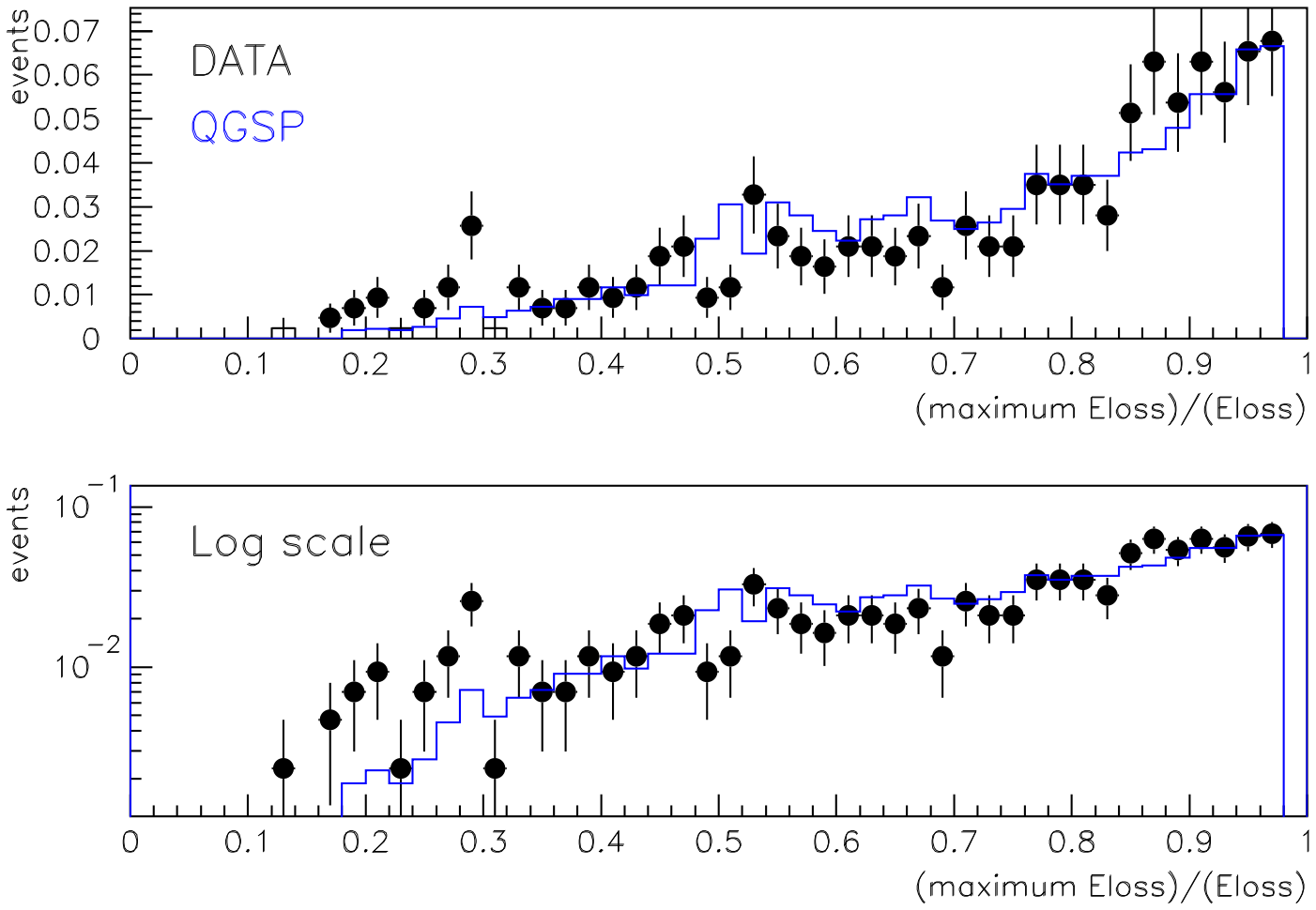

Entries 474
Mean 0.7472
RMS 0.2209
DATA
events
(maximum Eloss)/(Eloss)
Entries 1735
Mean 0.5238
RMS 0.2429
LHEP
events
(maximum Eloss)/(Eloss)
Entries 2825
Mean 0.7503
RMS 0.1911
QGSP
events
(maximum Eloss)/(Eloss)
Entries 3403
Mean 0.5838
RMS 0.2344
QGSC
events
(maximum Eloss)/(Eloss)

New


events
0.1
0.08
0.06
0.04
0.02
0
DATA
LHEP
QGSP
QGSC
0
0.2
0.4
0.6
0.8
1
(maximum Eloss)/(Eloss)
events
10^{-1}
10^{-2}
Log scale
0
0.2
0.4
0.6
0.8
1
(maximum Eloss)/(Eloss)

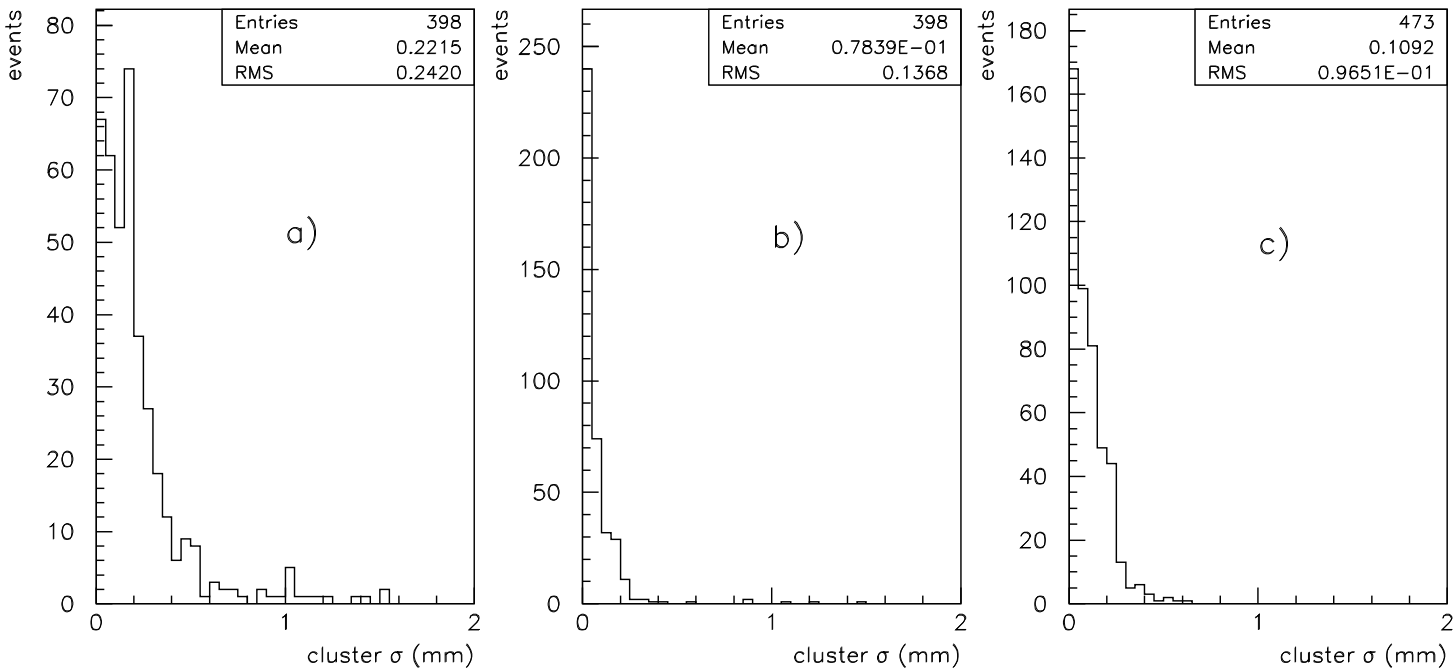
New

Comparing only DATA and QGSP removing the bin at 1.0 .



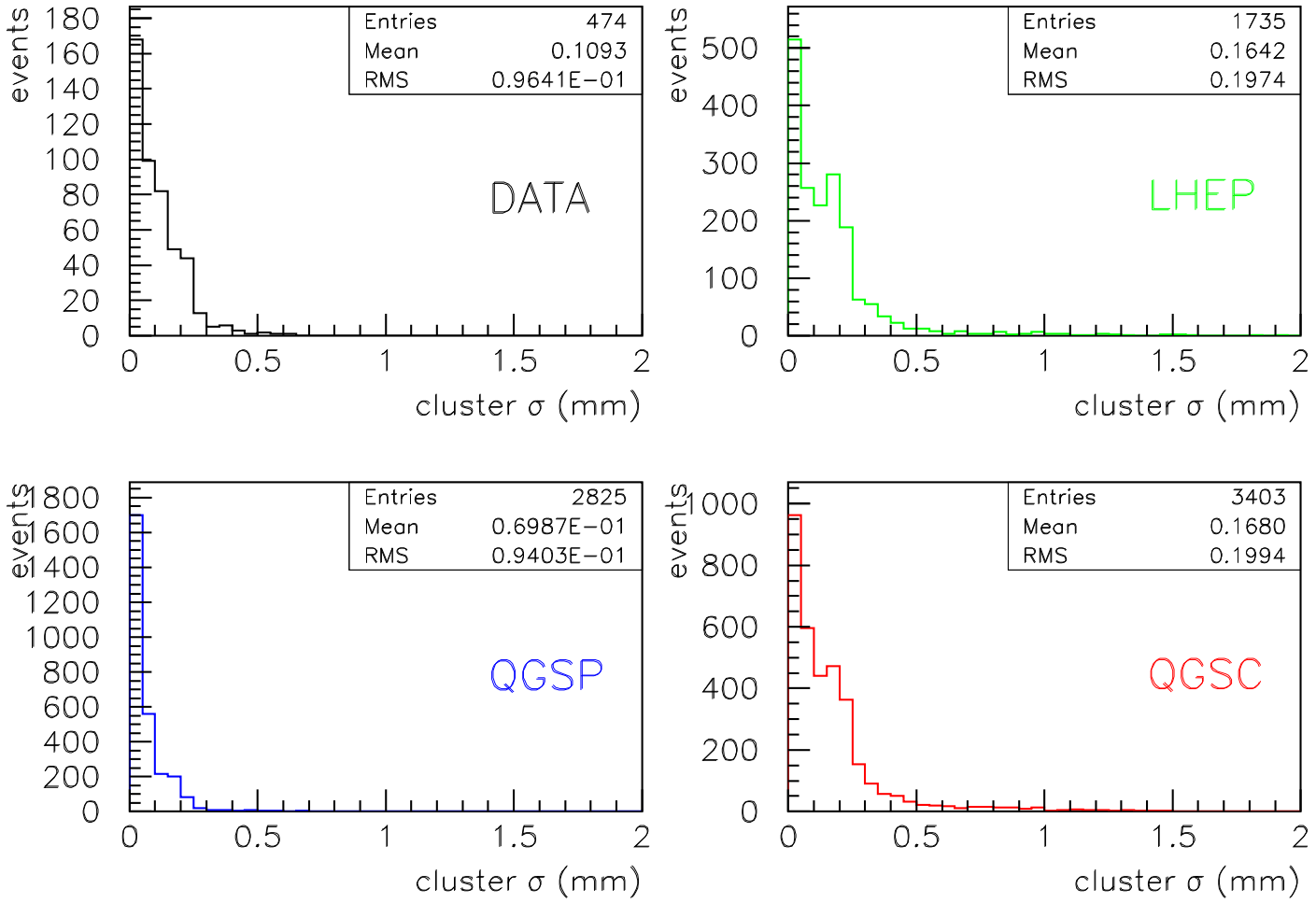
Old

Width of the cluster (mean of the distances of all digits from the cluster barycenter, weighted with the charge of the digits).

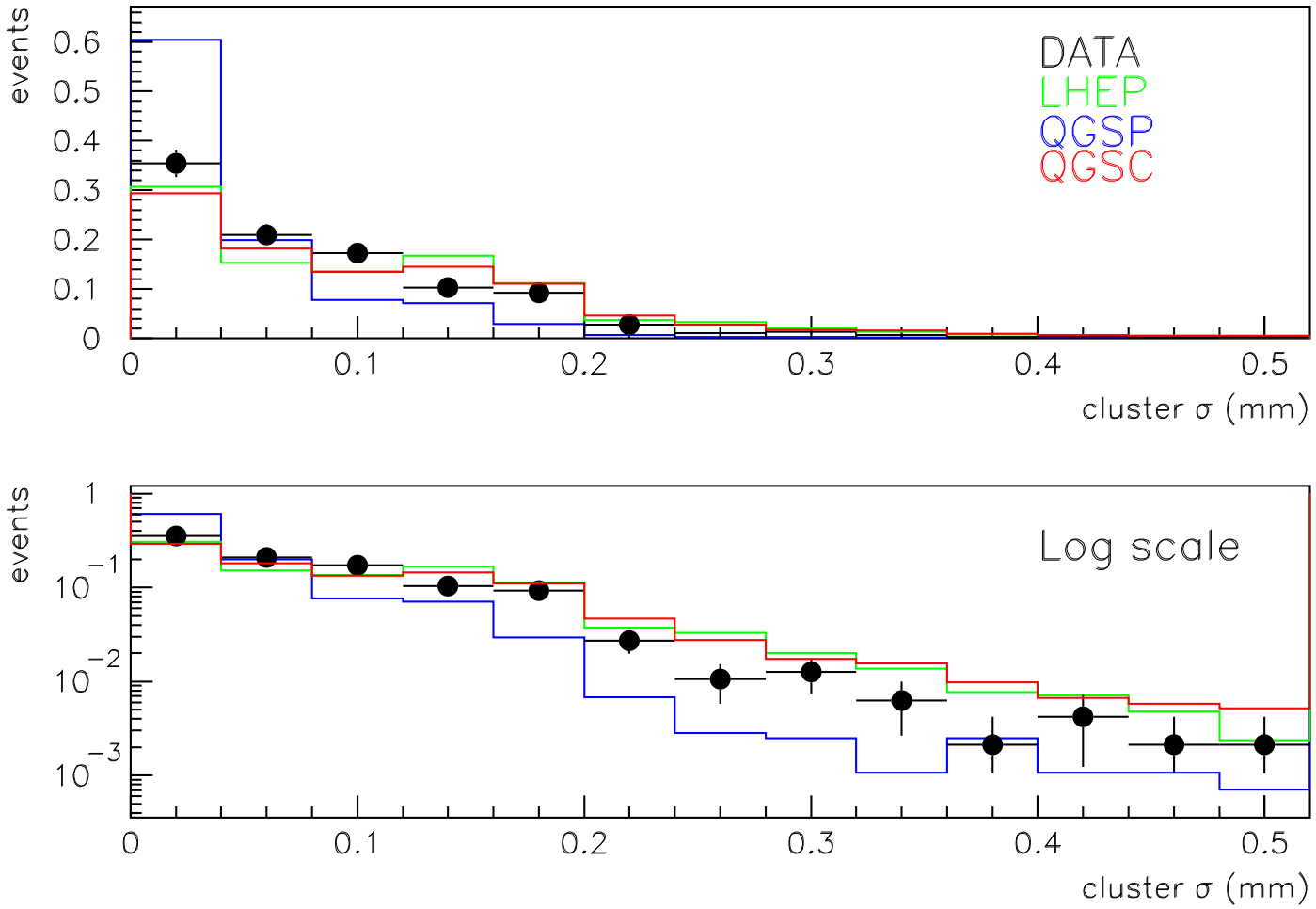


a) Param b) Theory c) Data

New

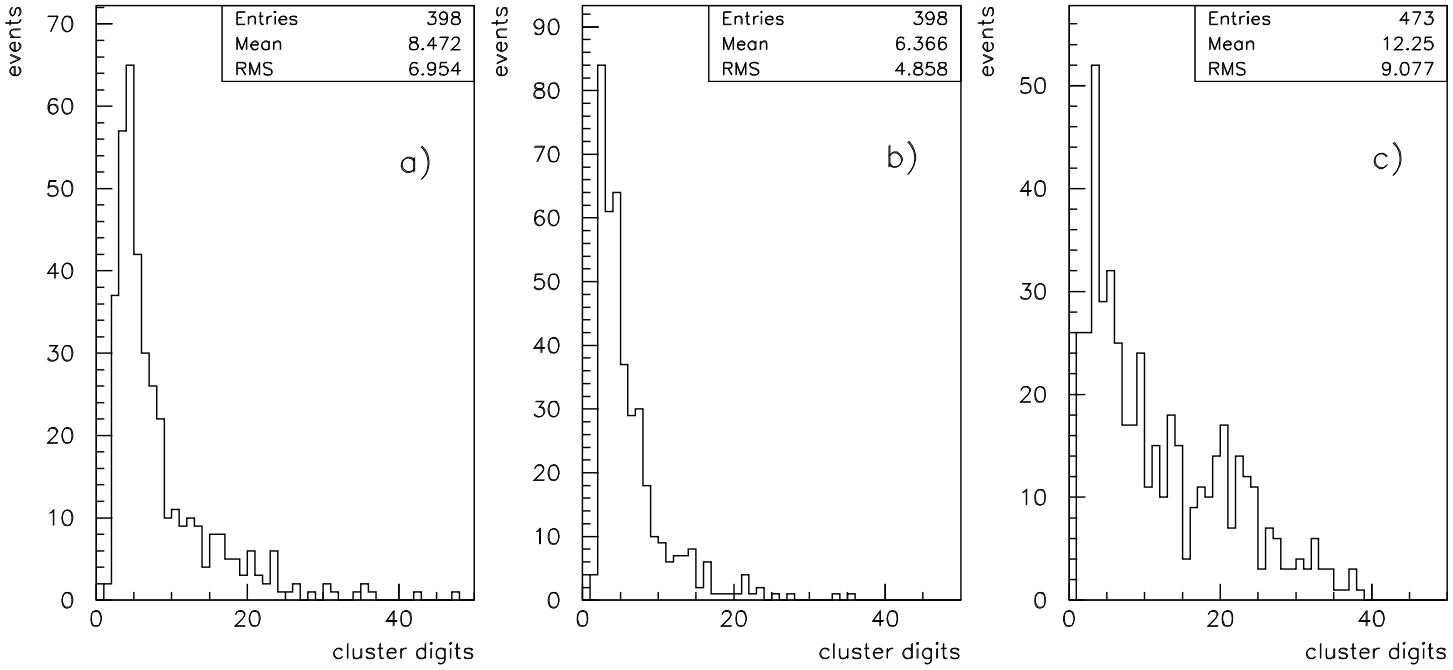

Entries 474
Mean 0.1093
RMS 0.9641E−01
DATA
events
cluster σ (mm)
Entries 1735
Mean 0.1642
RMS 0.1974
LHEP
events
cluster σ (mm)
Entries 2825
Mean 0.6987E−01
RMS 0.9403E−01
QGSP
events
cluster σ (mm)
Entries 3403
Mean 0.1680
RMS 0.1994
QGSC
events
cluster σ (mm)

New


events
0.6
0.5
0.4
0.3
0.2
0.1
0
DATA
LHEP
QGSP
QGSC
0
0.1
0.2
0.3
0.4
0.5
cluster σ (mm)
events
1
10^{-1}
10^{-2}
10^{-3}
Log scale
0
0.1
0.2
0.3
0.4
0.5
cluster σ (mm)

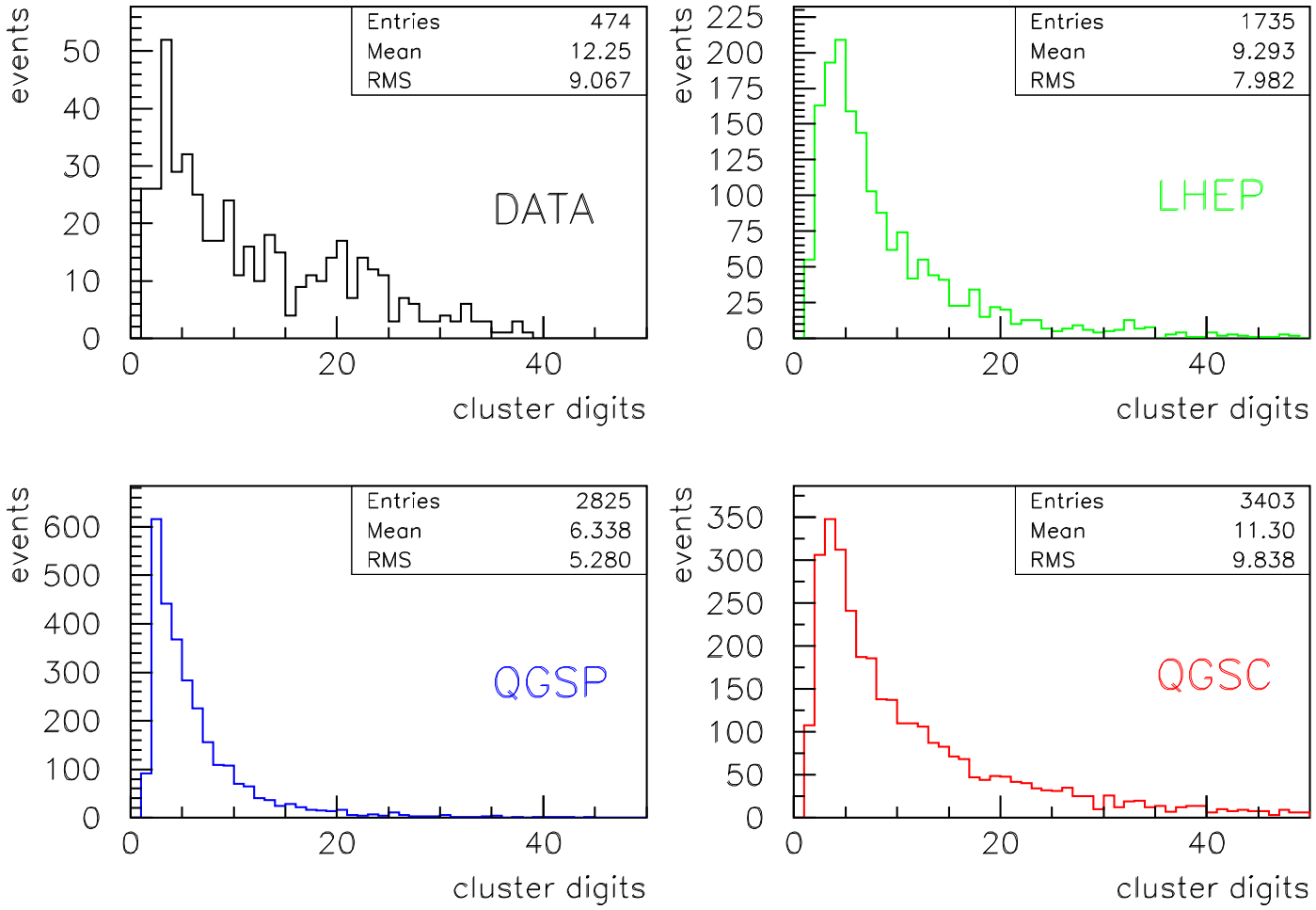
Old

Cluster size (number of digits in the cluster).

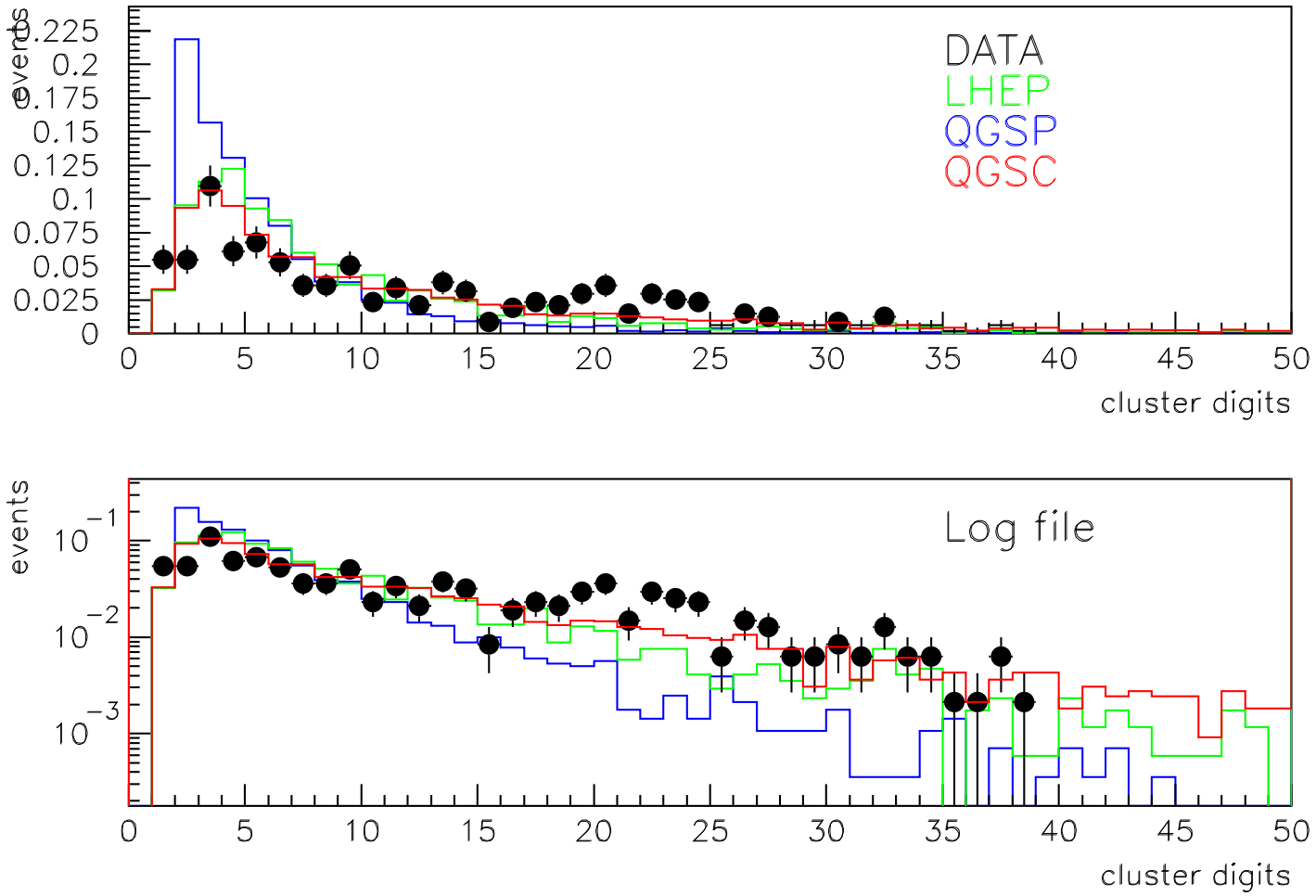


a) Param b) Theory c) Data

New

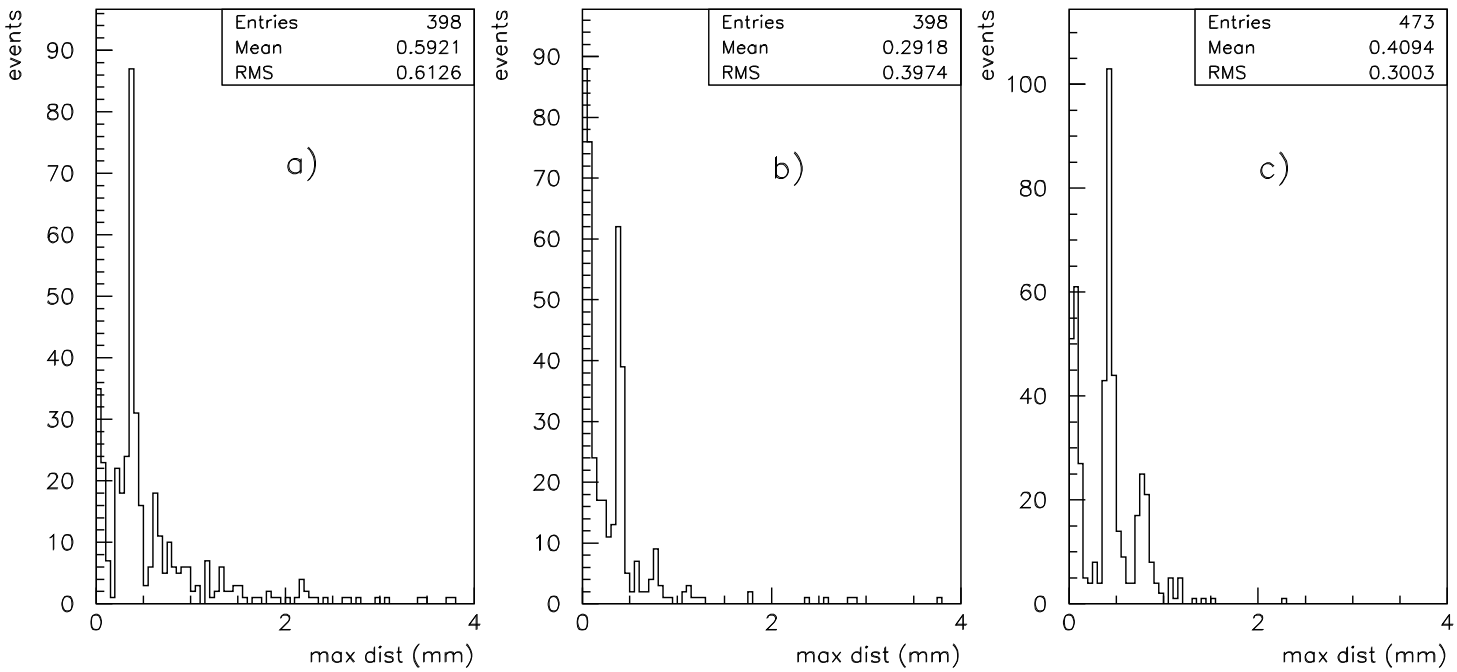

Entries 474
Mean 12.25
RMS 9.067
DATA
events
cluster digits
Entries 1735
Mean 9.293
RMS 7.982
LHEP
events
cluster digits
Entries 2825
Mean 6.338
RMS 5.280
QGSP
events
cluster digits
Entries 3403
Mean 11.30
RMS 9.838
QGSC
events
cluster digits

New


events
0.225
0.2
0.175
0.15
0.125
0.1
0.075
0.05
0.025
0
DATA
LHEP
QGSP
QGSC
0 5 10 15 20 25 30 35 40 45 50
cluster digits
events
10^{-1}
10^{-2}
10^{-3}
Log file
0 5 10 15 20 25 30 35 40 45 50
cluster digits

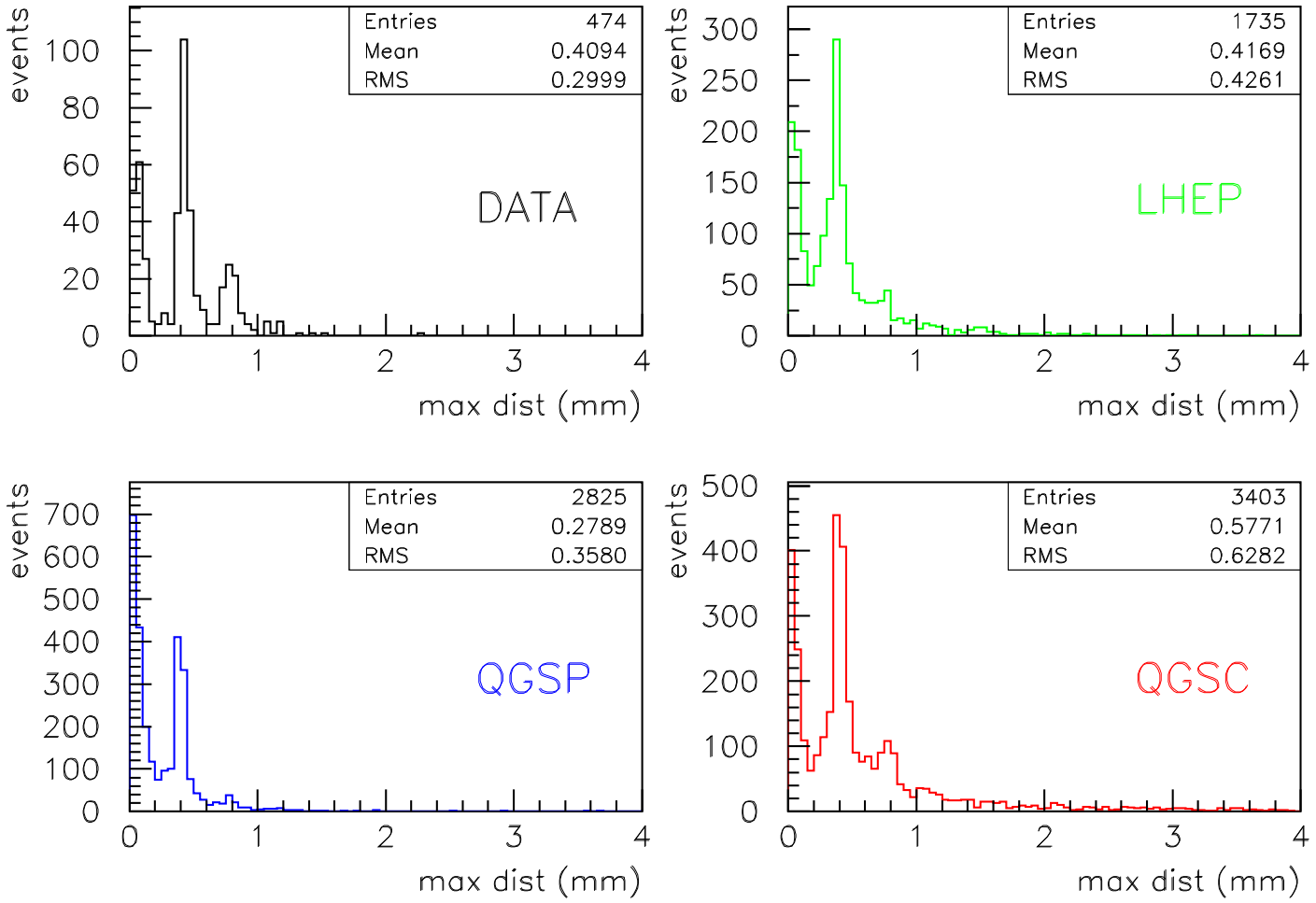
Old

Distance of the farthest digit from the cluster barycenter (the peak structure corresponds to the 400 μm pixel length).

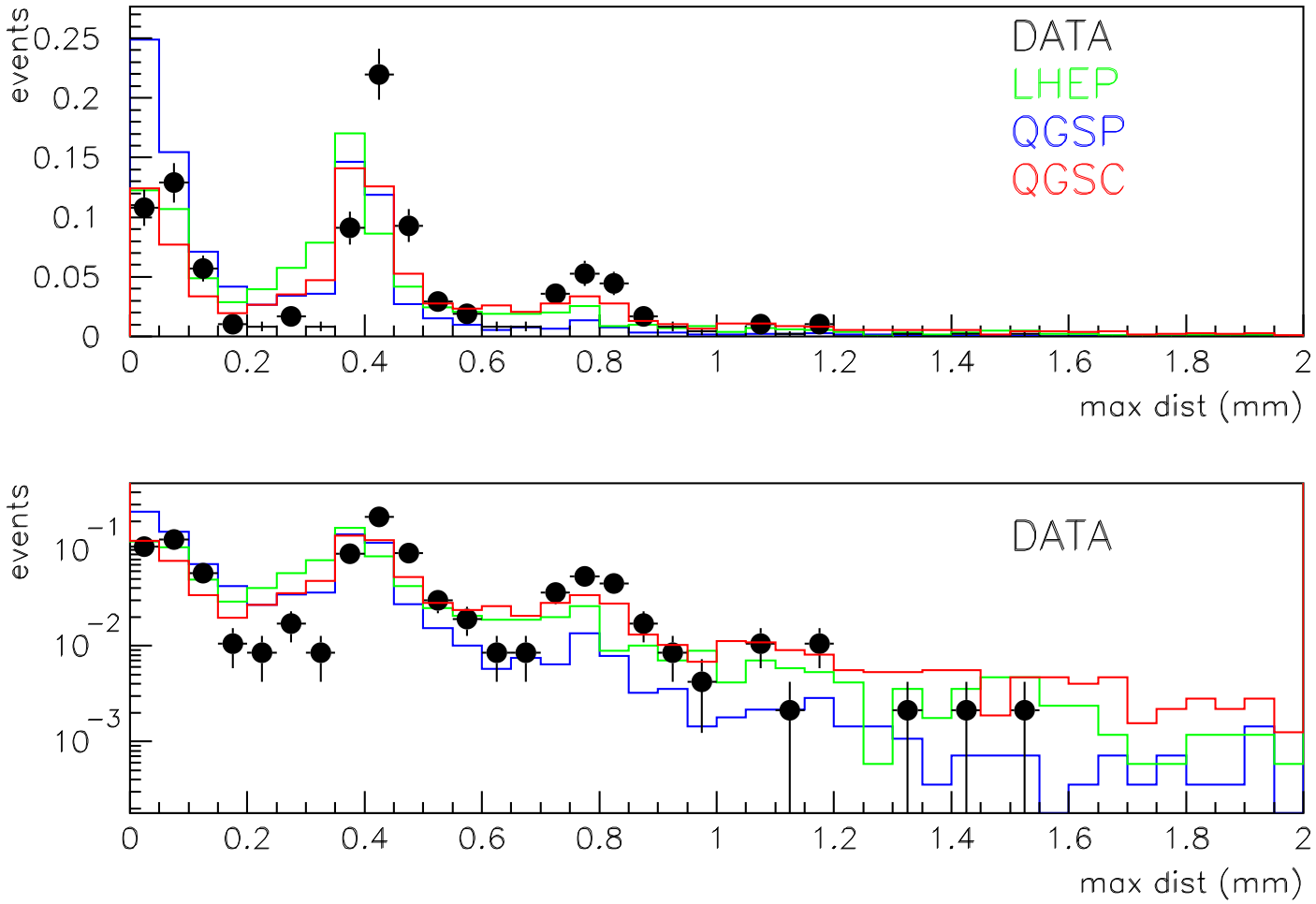


a) Param b) Theory c) Data

New


Entries 474
Mean 0.4094
RMS 0.2999
DATA
events
max dist (mm)
Entries 1735
Mean 0.4169
RMS 0.4261
LHEP
events
max dist (mm)
Entries 2825
Mean 0.2789
RMS 0.3580
QGSP
events
max dist (mm)
Entries 3403
Mean 0.5771
RMS 0.6282
QGSC
events
max dist (mm)

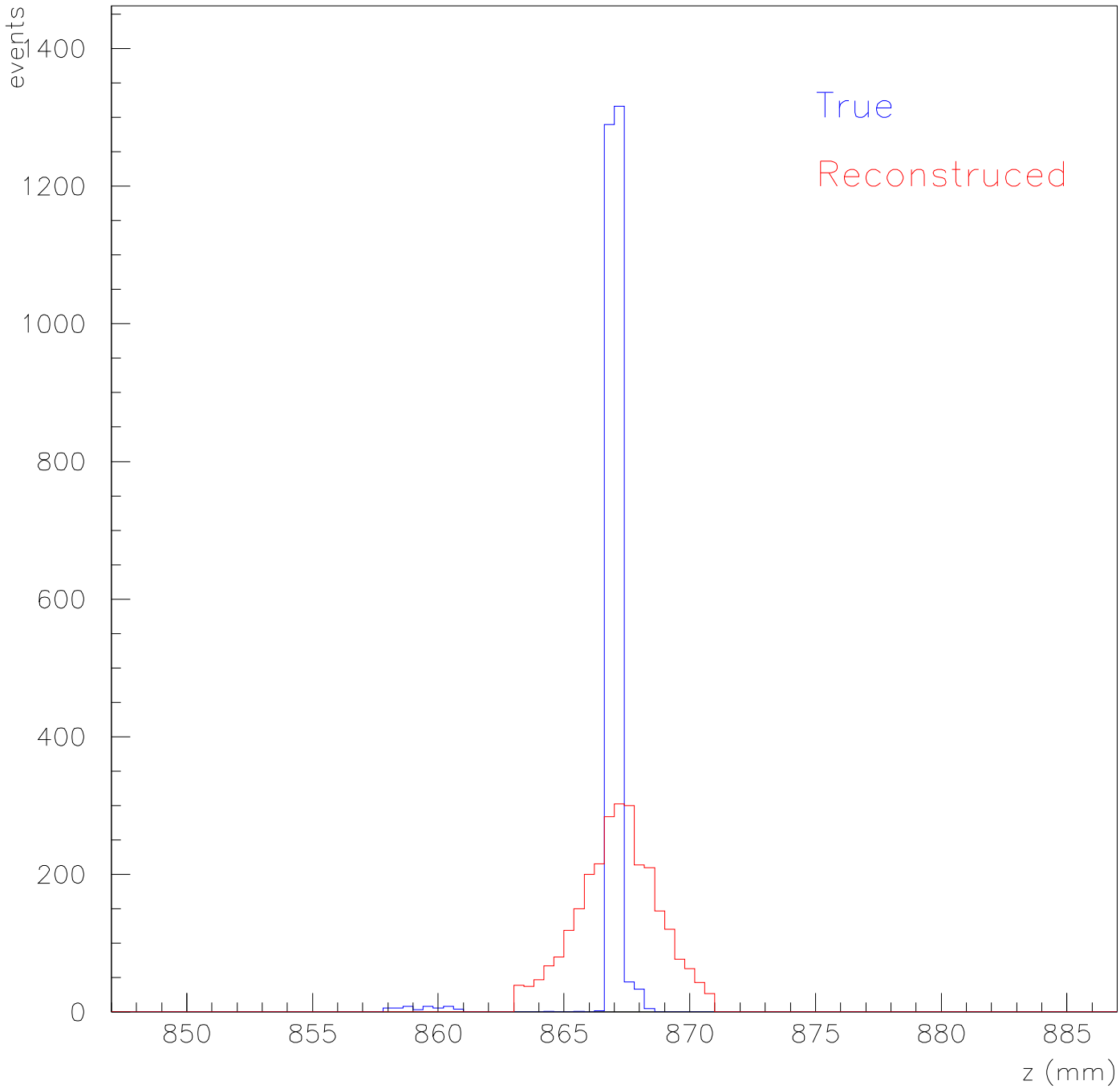
New


events
0.25
0.2
0.15
0.1
0.05
0
DATA
LHEP
QGSP
QGSC
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
max dist (mm)
events
10^{-1}
10^{-2}
10^{-3}
DATA
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
max dist (mm)

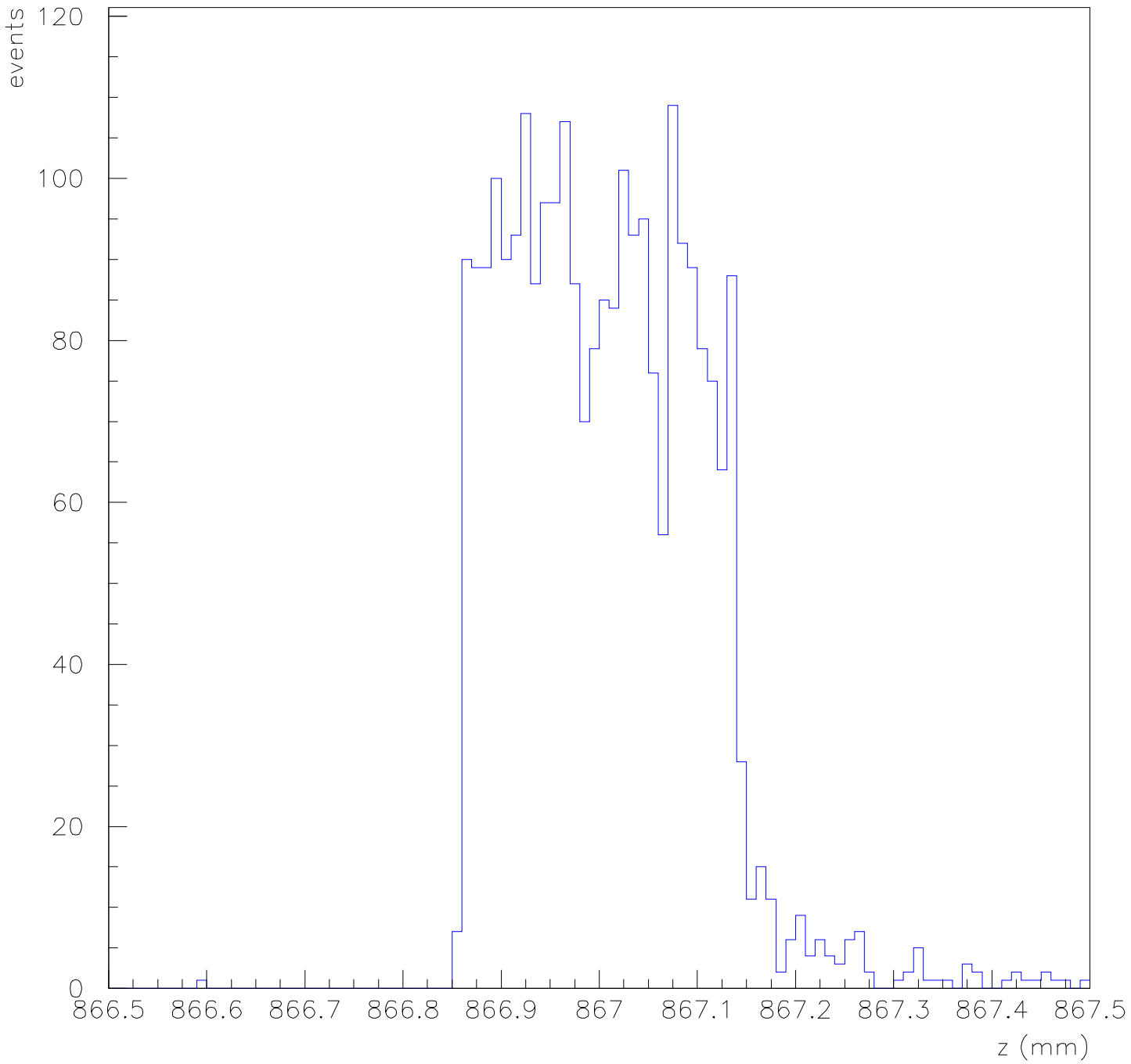
Some checks

- Do the interactions happen in the pixel sensor?
- Does the shift in z affect the distributions?
- Can we adjust "by hand" the calibration ?
- Are the energy-loss distributions different for: p, π^+, K^+ ?
- Study the spatial properties of the vertex cluster separately in x and y .
- Do the distributions change for small variations of the beam spot ?
- Do the distributions change by varying the pixel clustering zero-suppression threshold ?
- Look at the other clusters (the ones not associated with the hadronic interaction).
- Are the peaks at 1 in Emax/Eloss and at 0 in cluster size consistent?
- Which is the eta acceptance?

Vertex Resolution After All Cuts

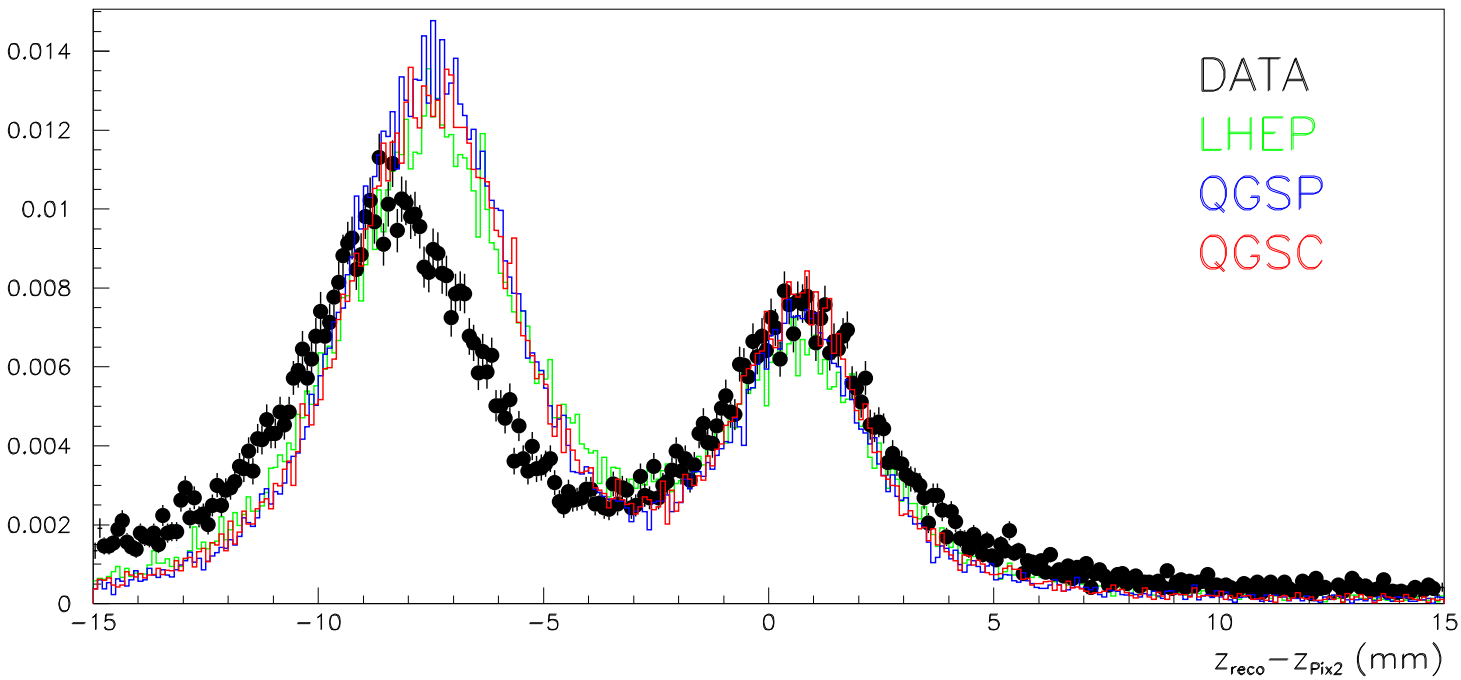


Vertex Resolution After All Cuts (cont.)



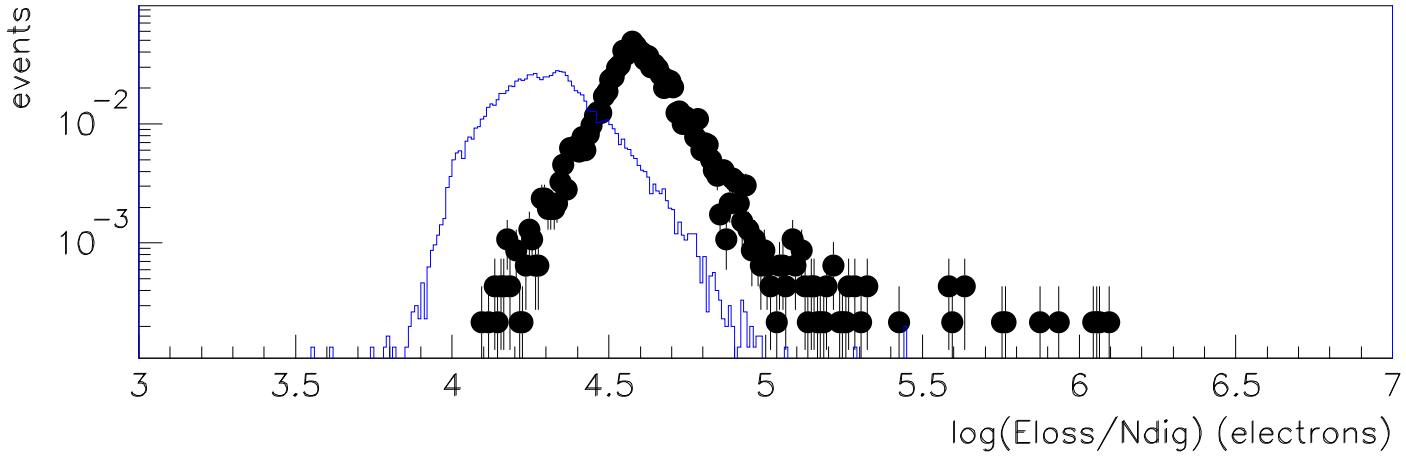
Shift in z

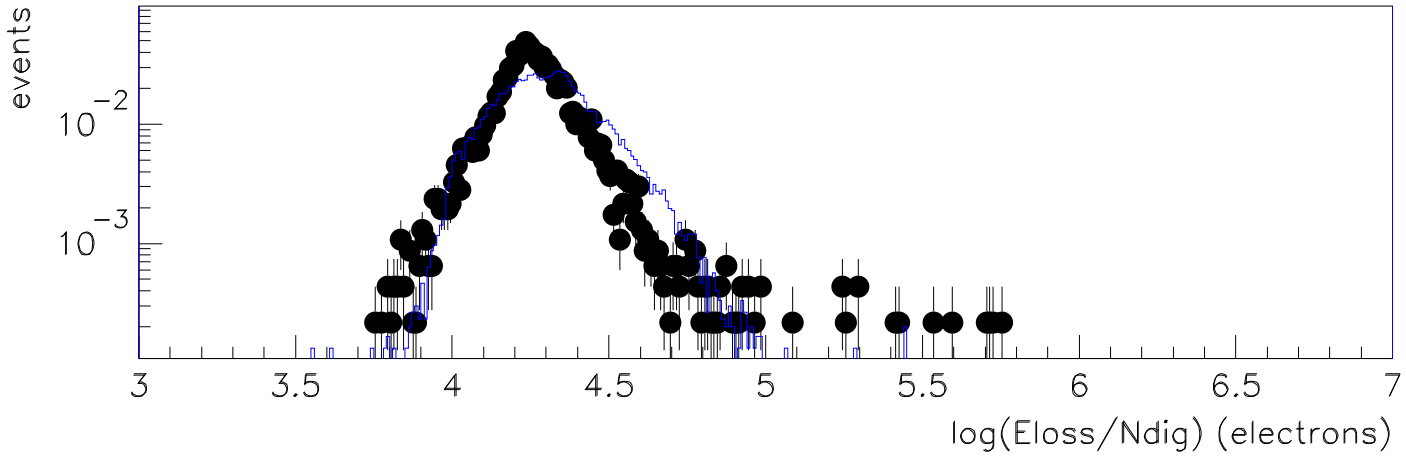
By moving a bit the z positions of Pix2 and/or of silicon planes it is possible to match data and simulation in at least one of the two peaks. But this does not affect the cluster distributions.



Shift in Eloss/Ndig

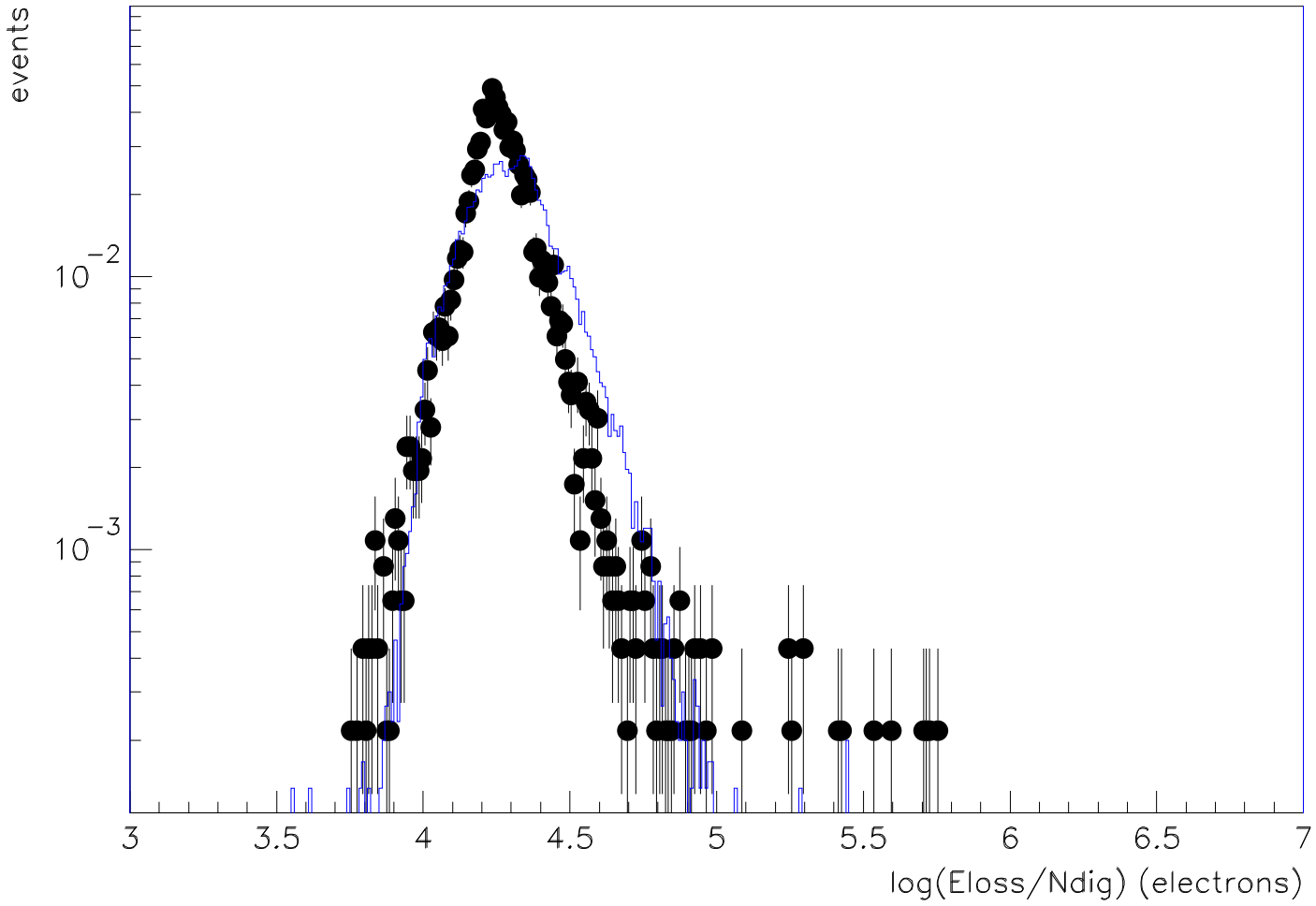
The shift corresponds to a factor data/sim of 2.24 .





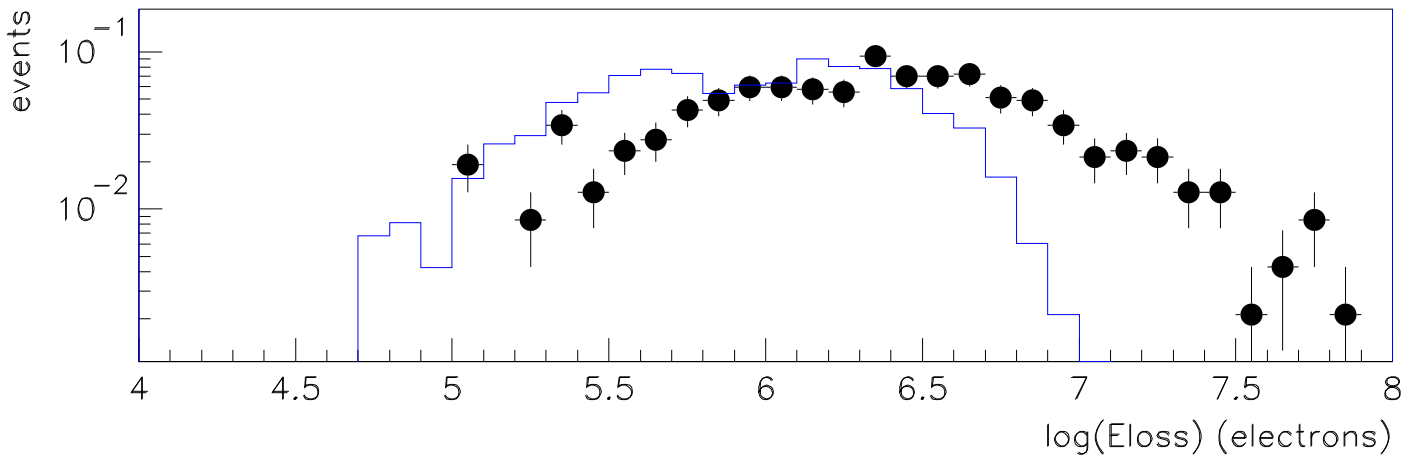
Shift in Eloss/Ndig (cont.)

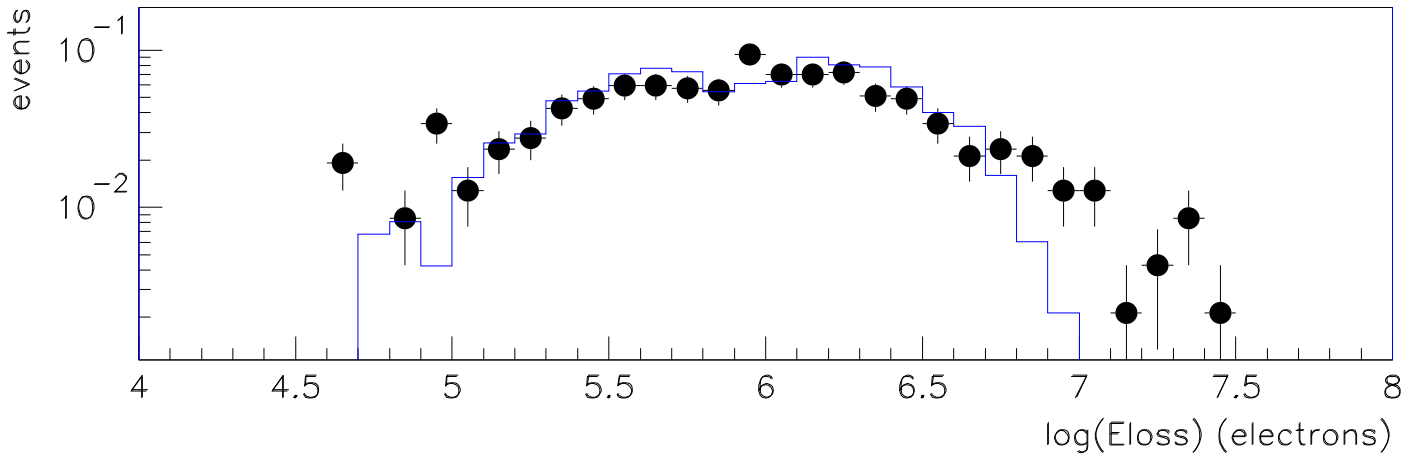
The narrower right tail of the data w.r.t. simulation is consistent with a saturation effect in the charge calibration (but also with the fact that the cluster size of data is larger than in the simulation!).



Shift in Eloss

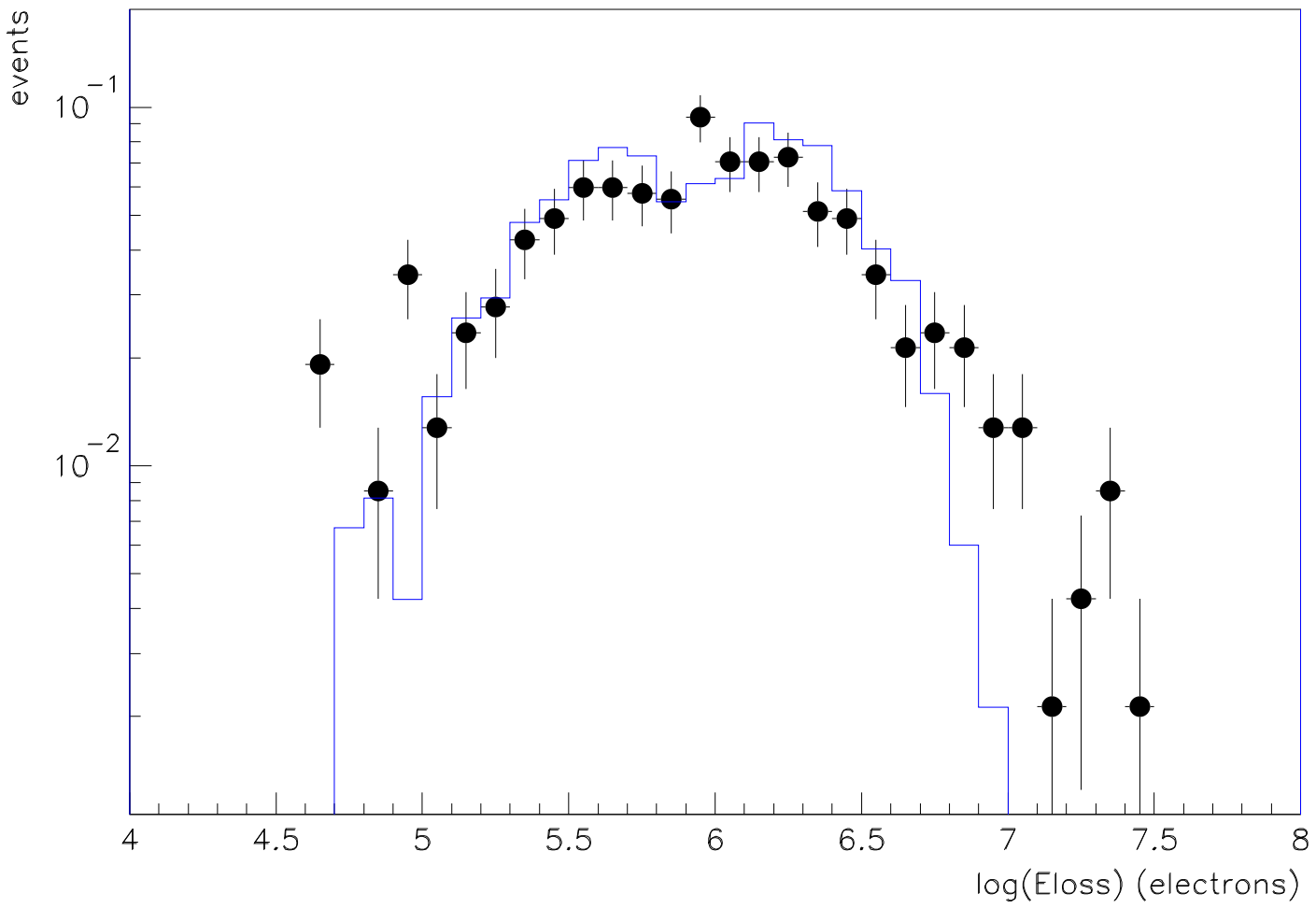
The shift corresponds to a factor of data/sim 3.16 .





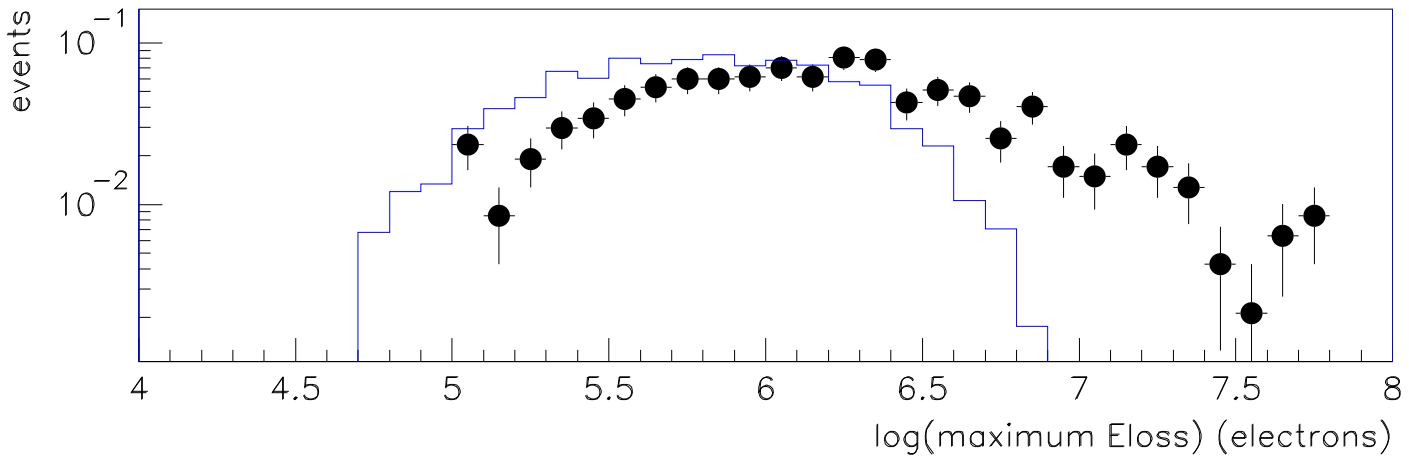
Shift in Eloss (cont.)

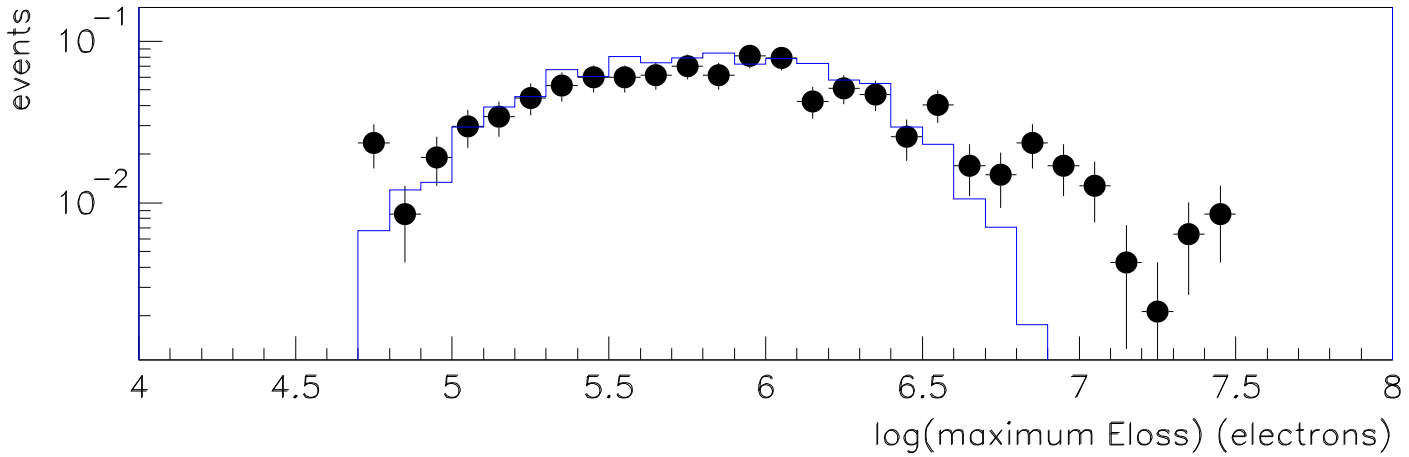
The broader right tail of the data w.r.t. simulation is *not* consistent with a saturation effect in the charge calibration.



Shift in Emax

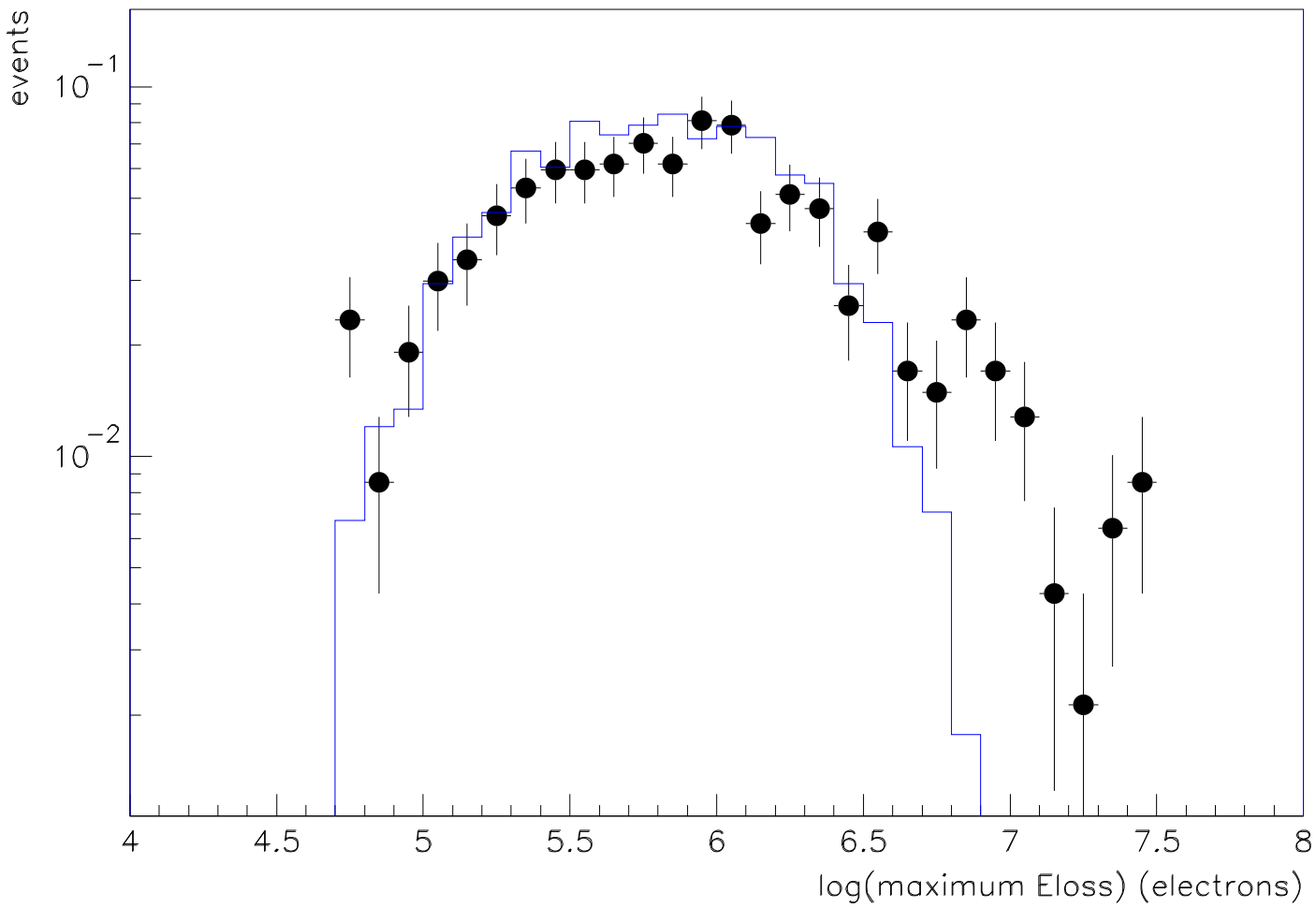
The shift corresponds to a factor data/sim of 2.50 .



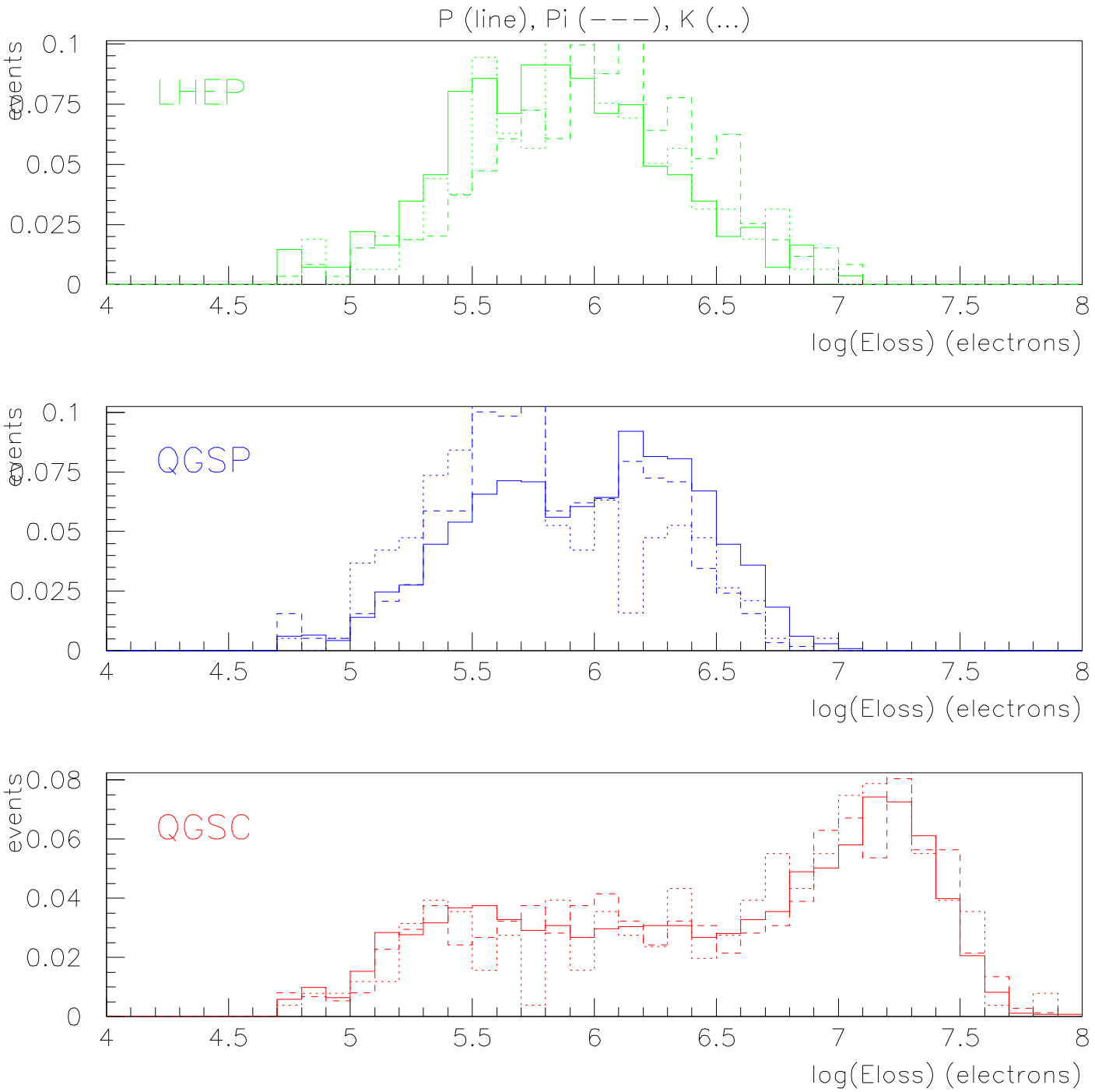


Shift in Emax (cont.)

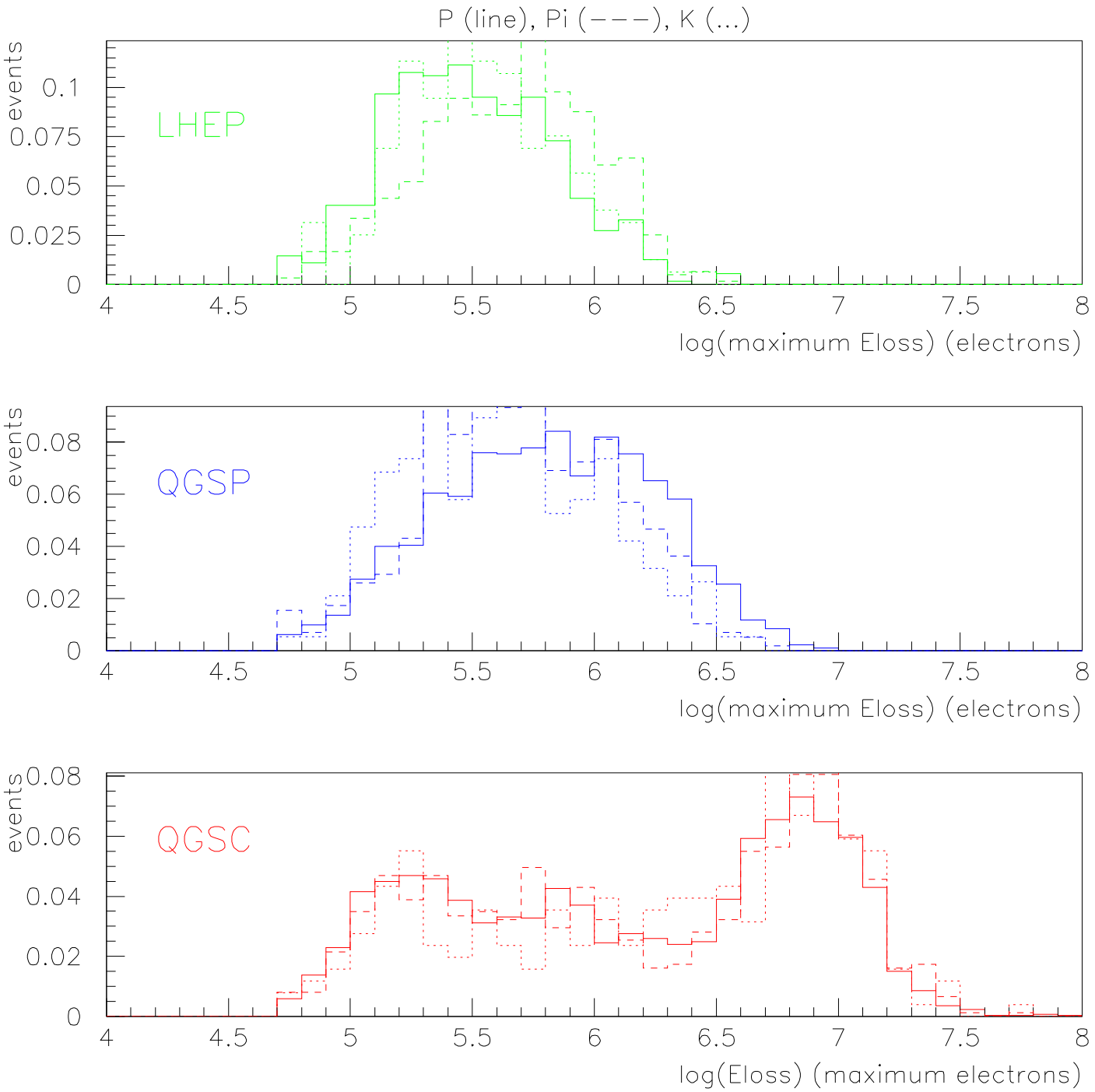
The broader right tail of the data w.r.t. simulation is *not* consistent with a saturation effect in the charge calibration.



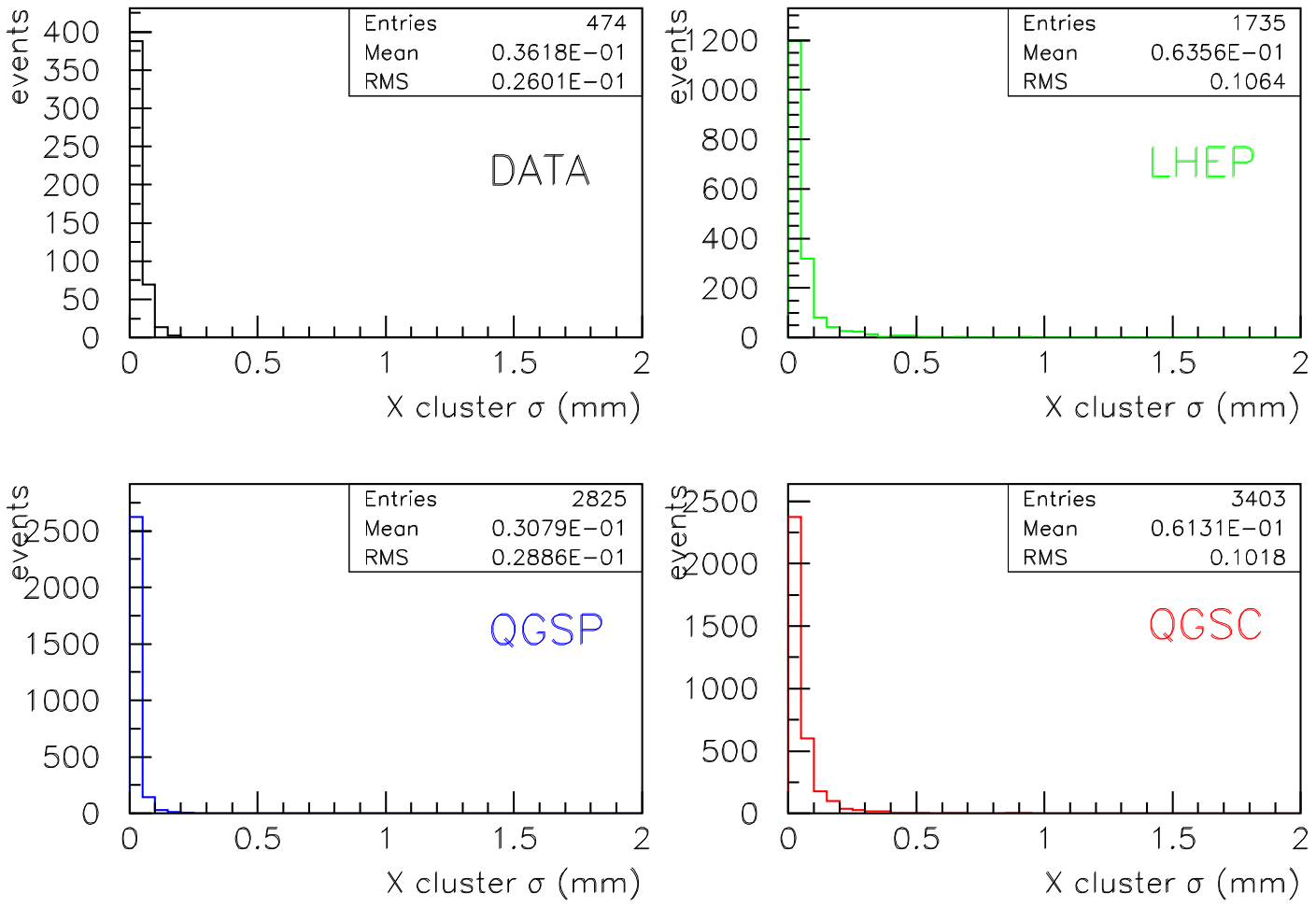
Eloss p, π^+, K^+



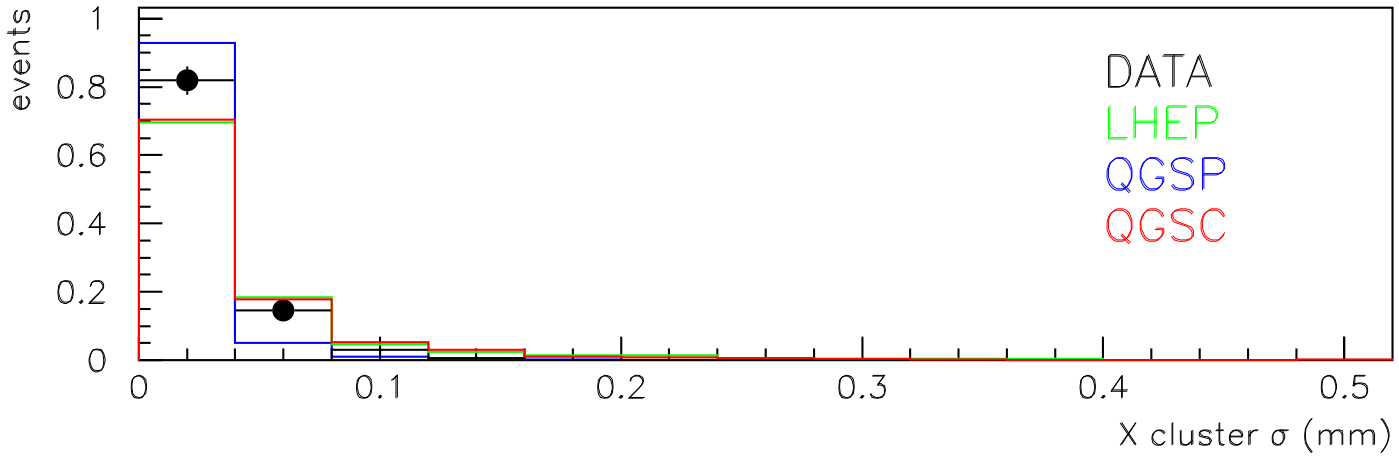
Emax p, π^+, K^+

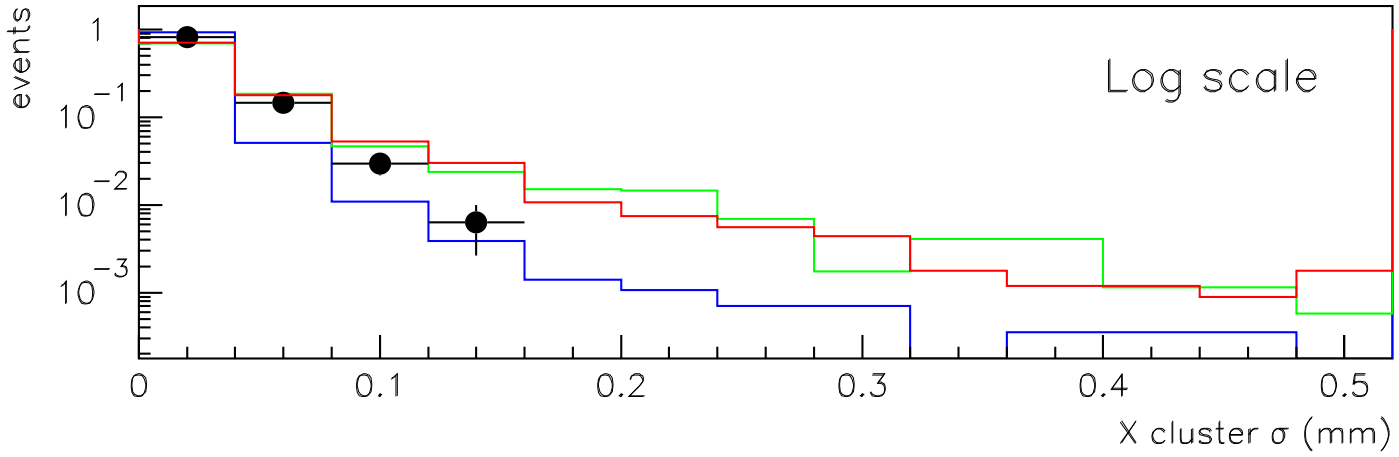

P (line), Pi (---), K (...)
events
LHEP
0.1
0.075
0.05
0.025
0
4
4.5
5
5.5
6
6.5
7
7.5
8
log(maximum Eloss) (electrons)
events
QGSP
0.08
0.06
0.04
0.02
0
log(maximum Eloss) (electrons)
events
QGSC
0.08
0.06
0.04
0.02
0
log(Eloss) (maximum electrons)

Cluster width, in X

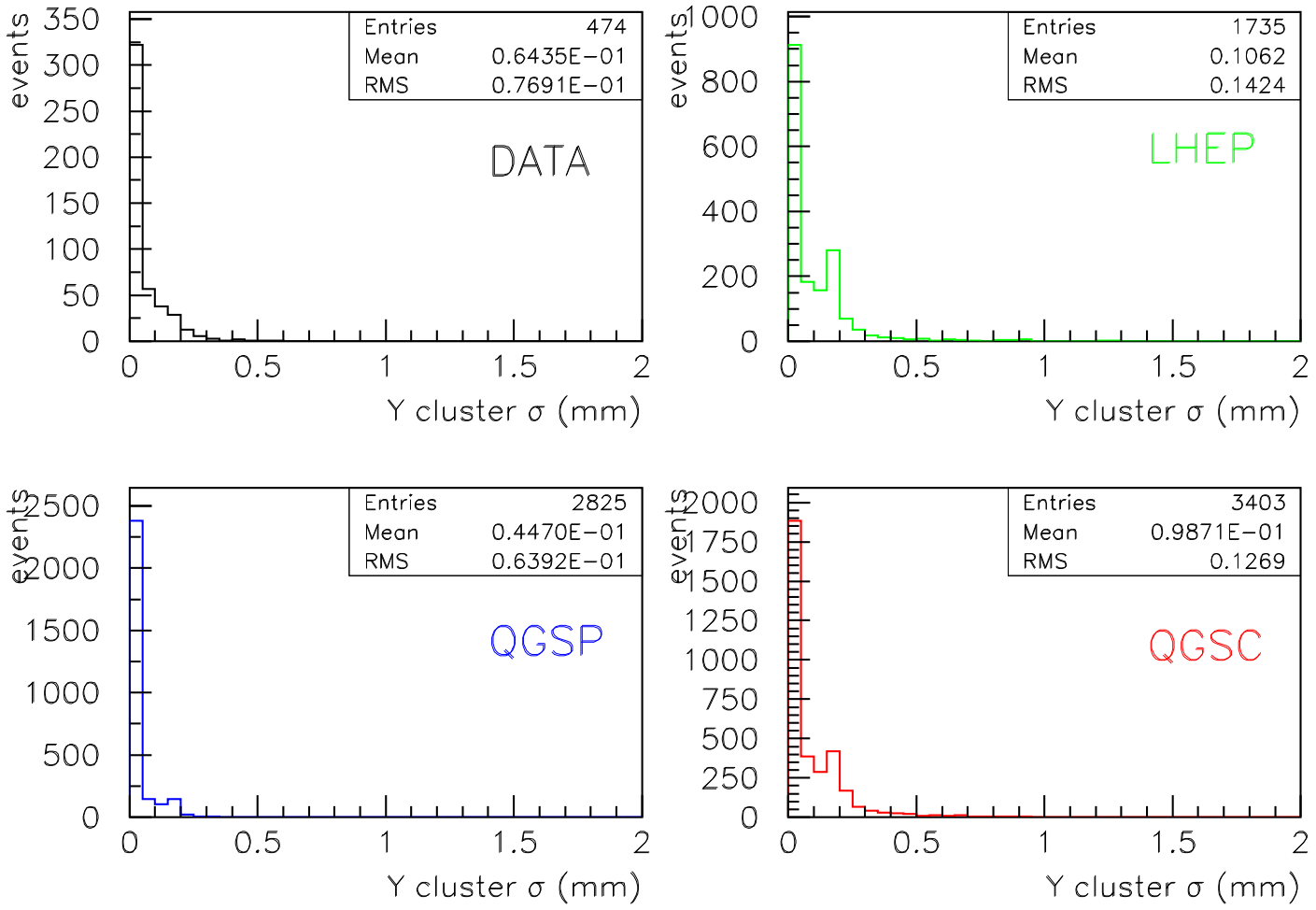


Cluster width, in X (cont.)

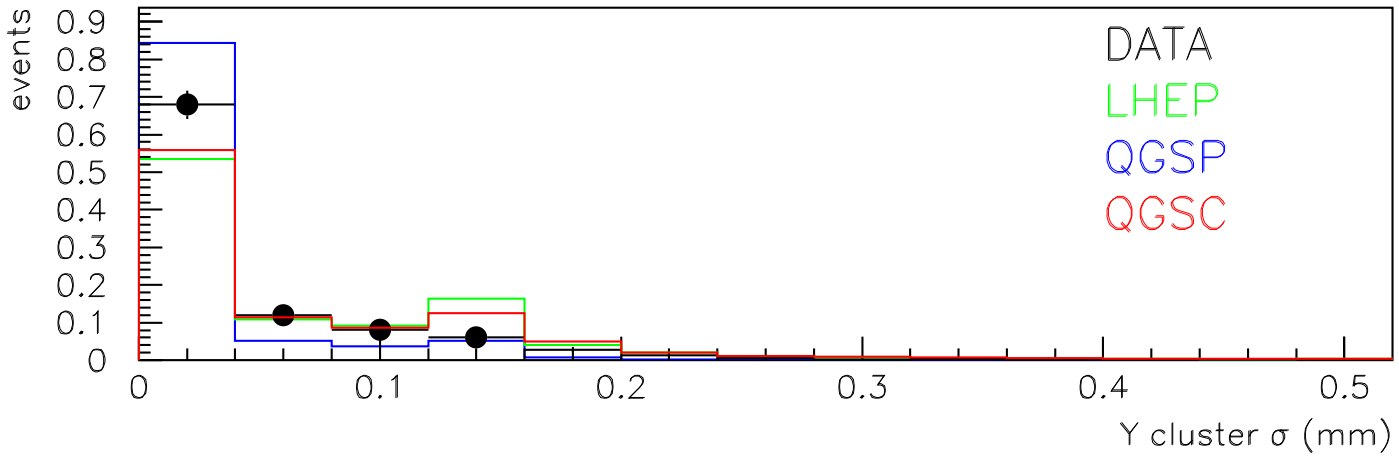


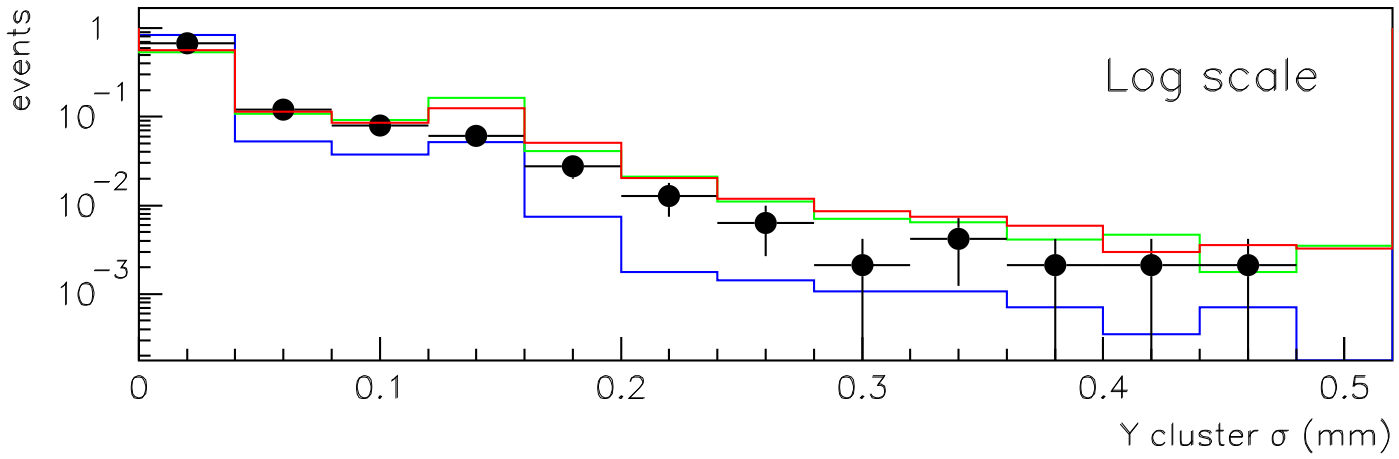


Cluster width, in Y

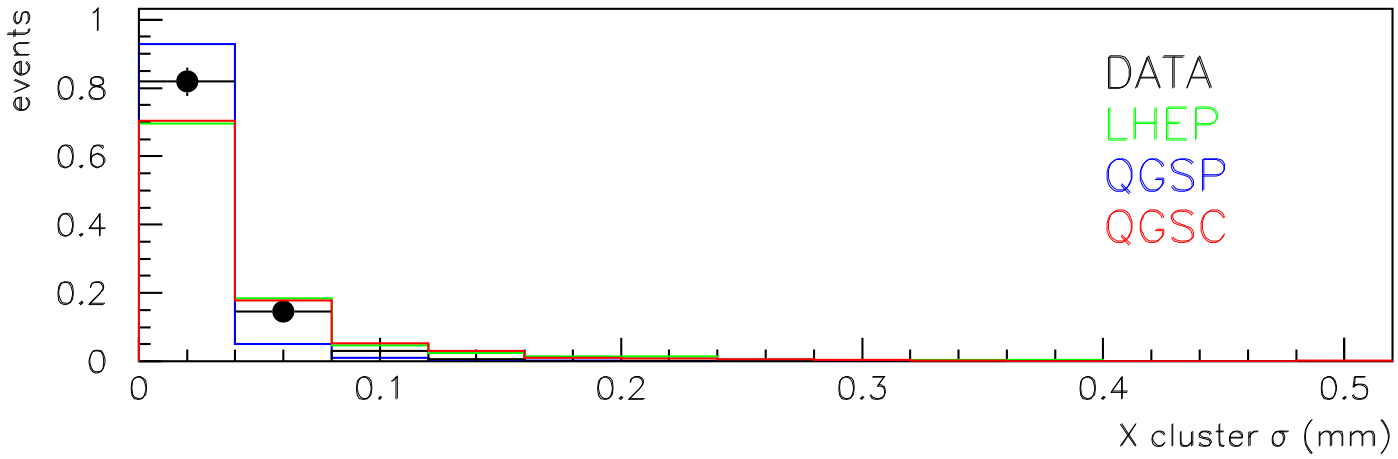


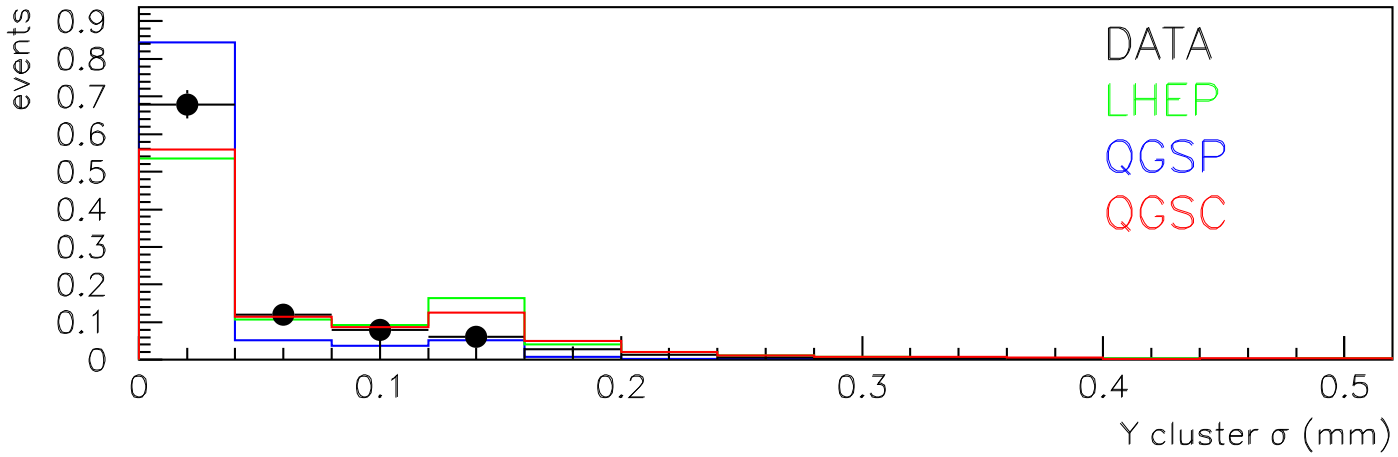
Cluster width, in Y (cont.)



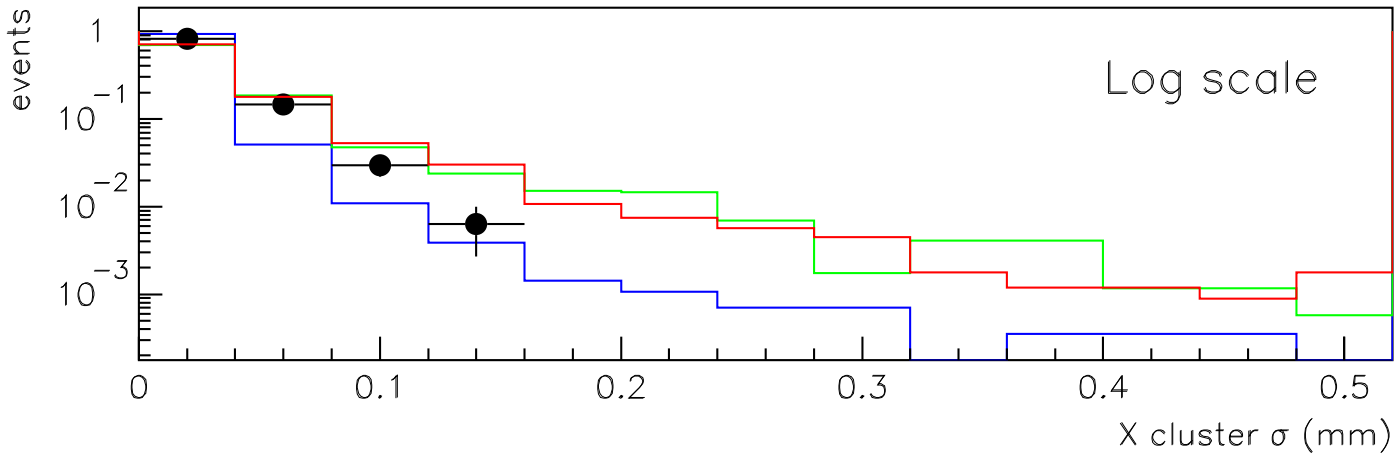


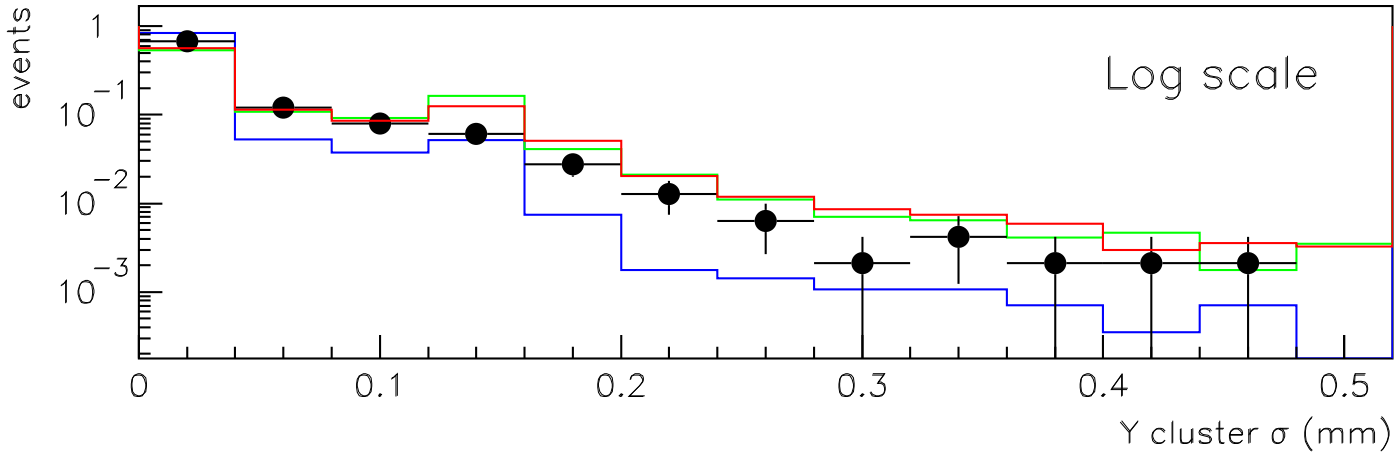
Cluster width, in X and Y



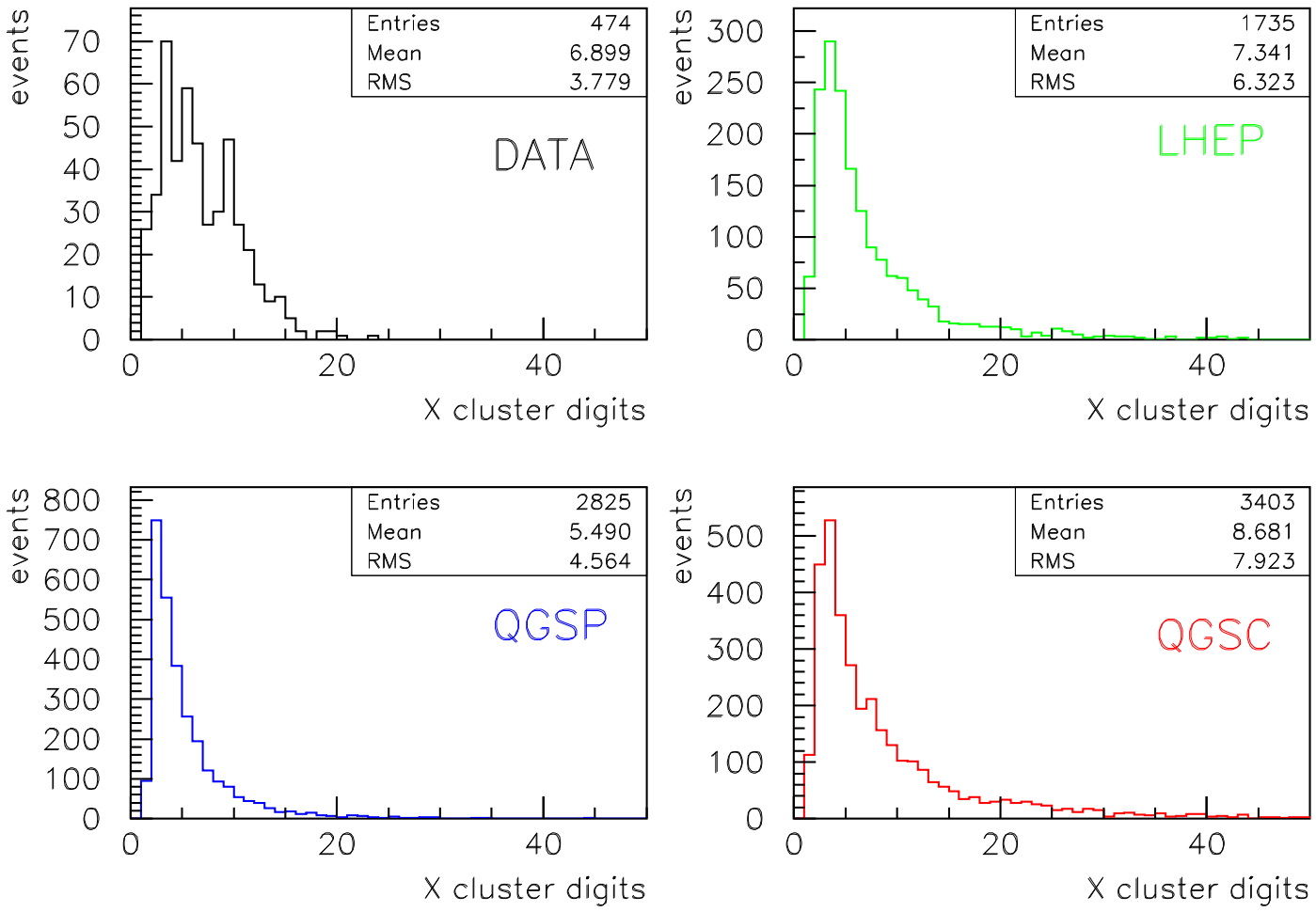


Cluster width, in X and Y (cont.)

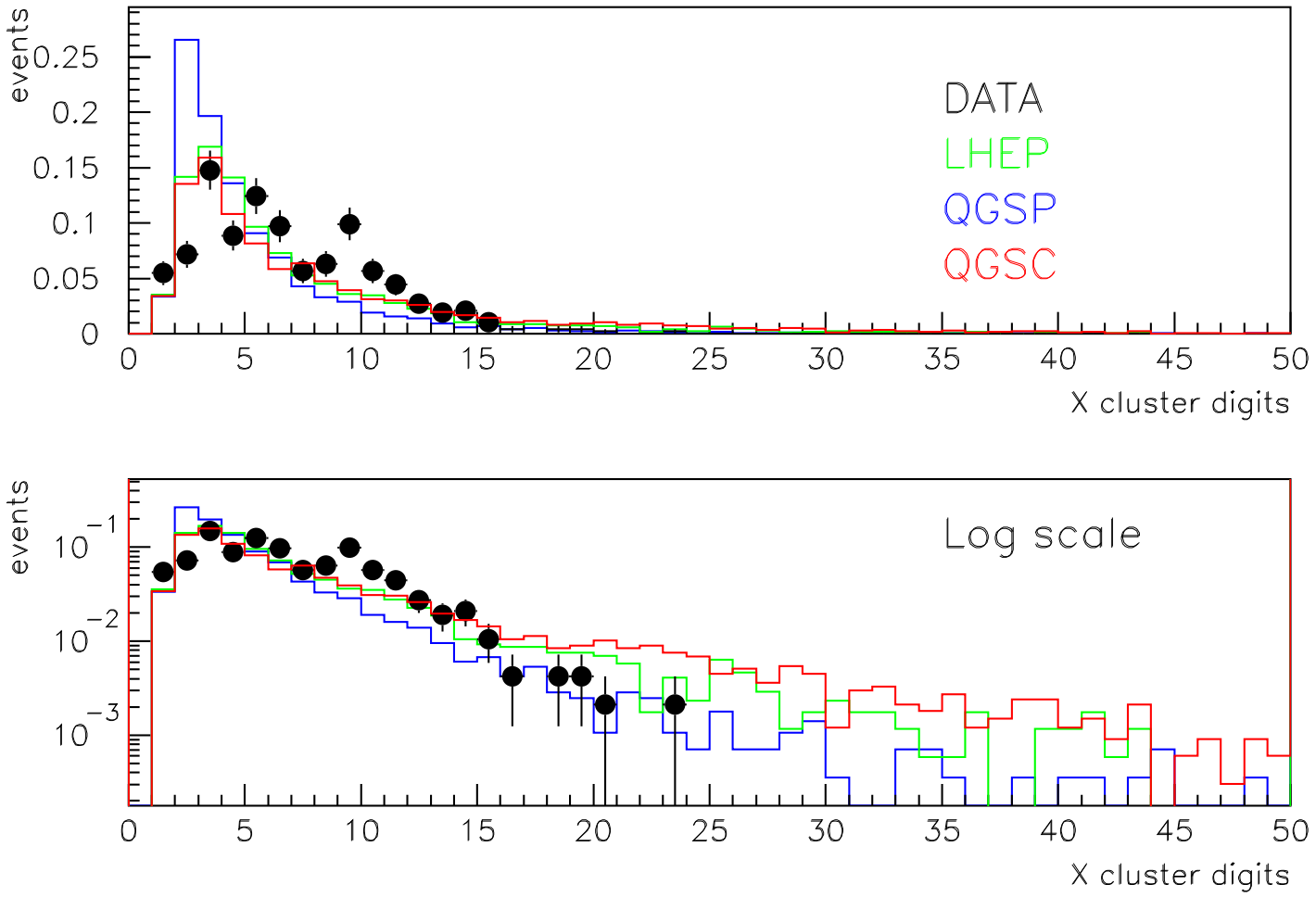




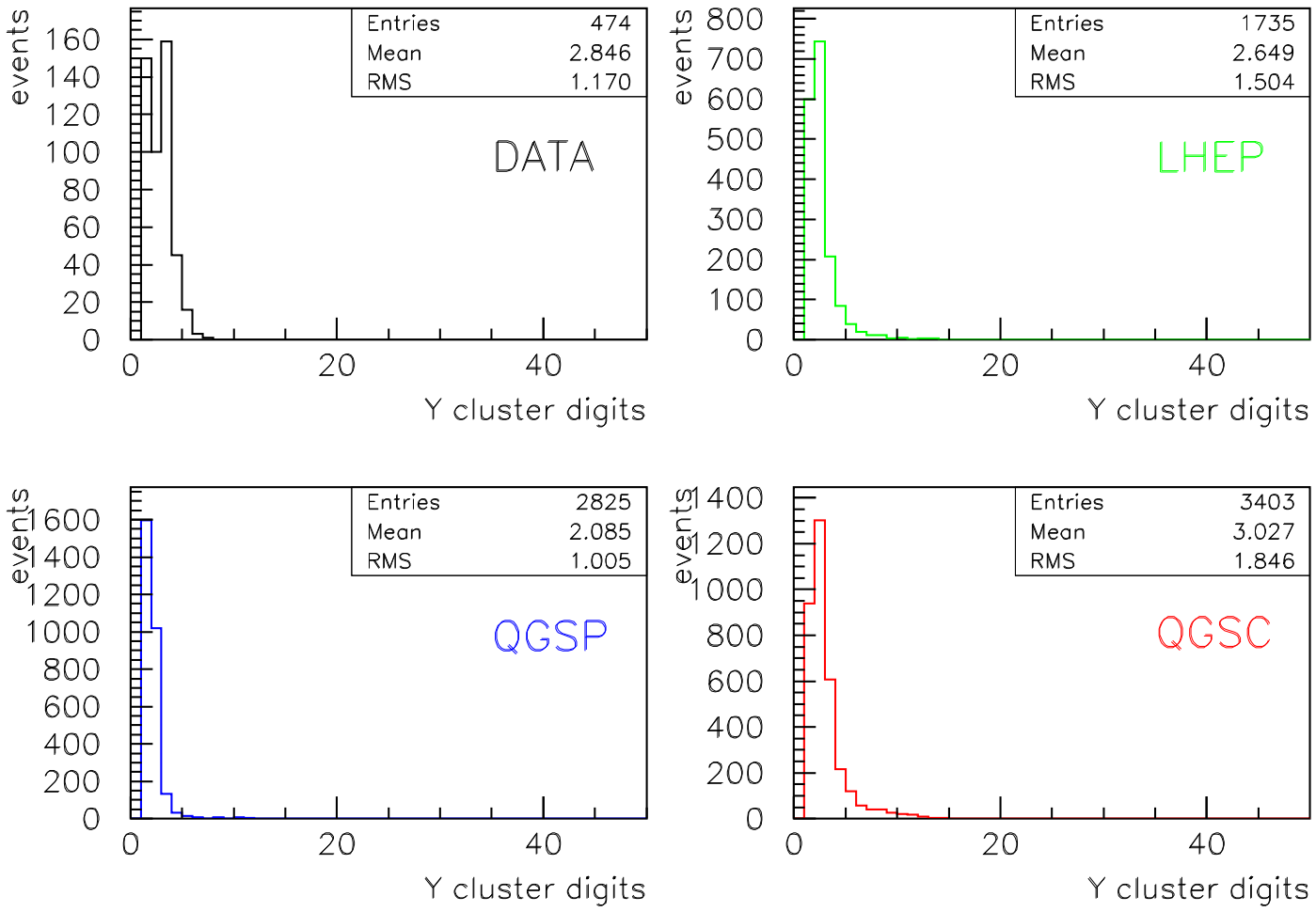
Cluster size, in X



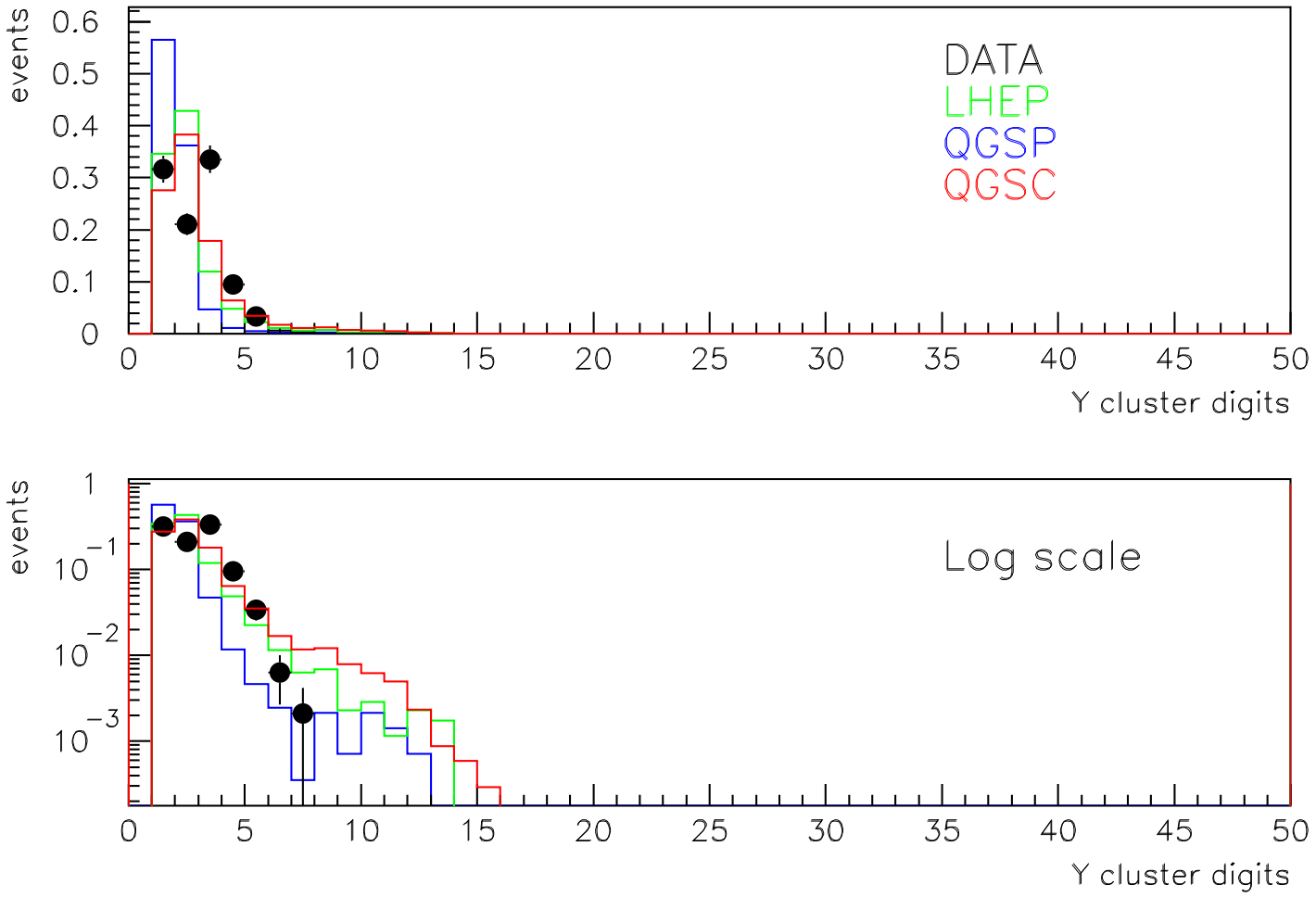
Cluster size, in X (cont.)



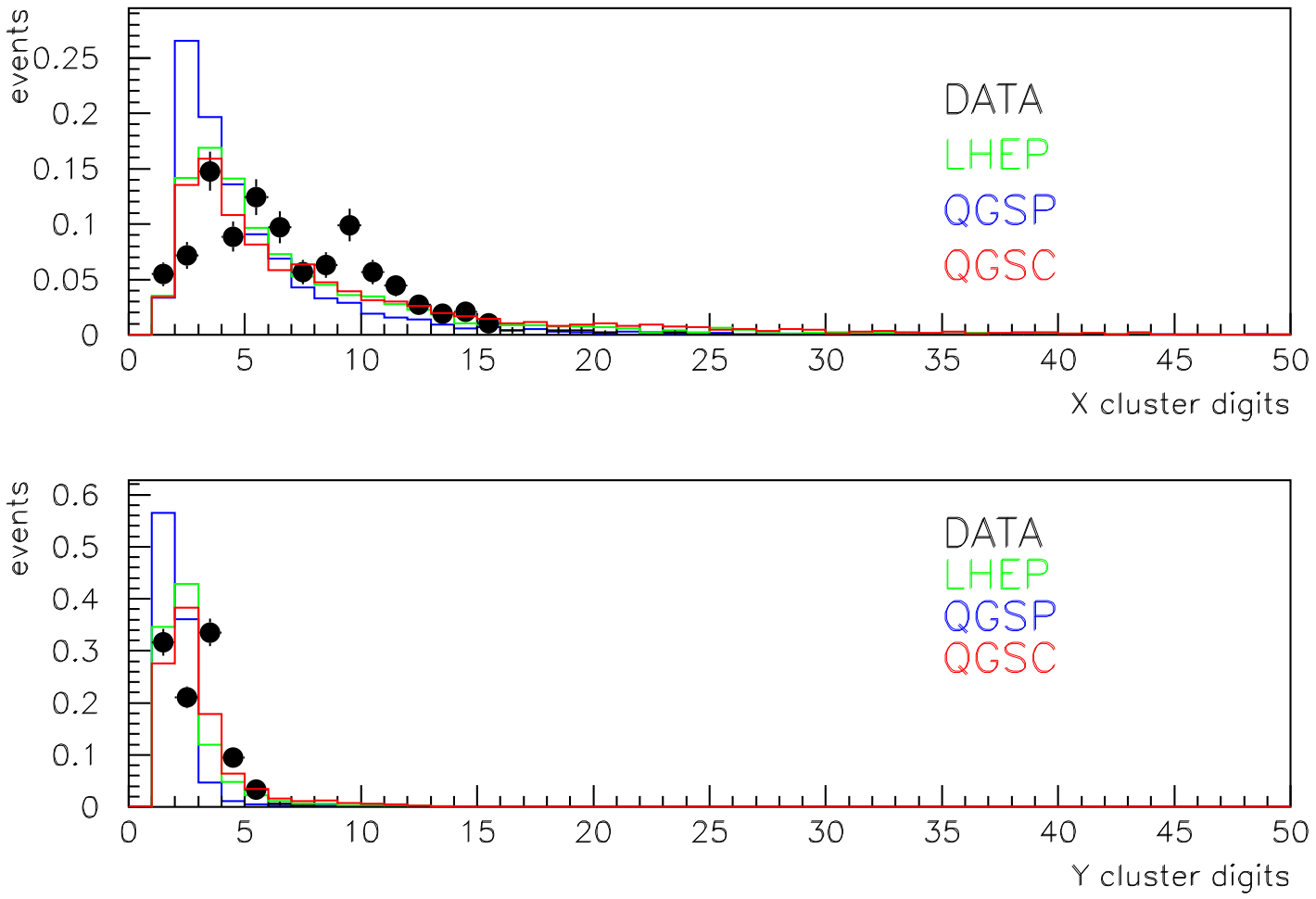
Cluster size, in Y



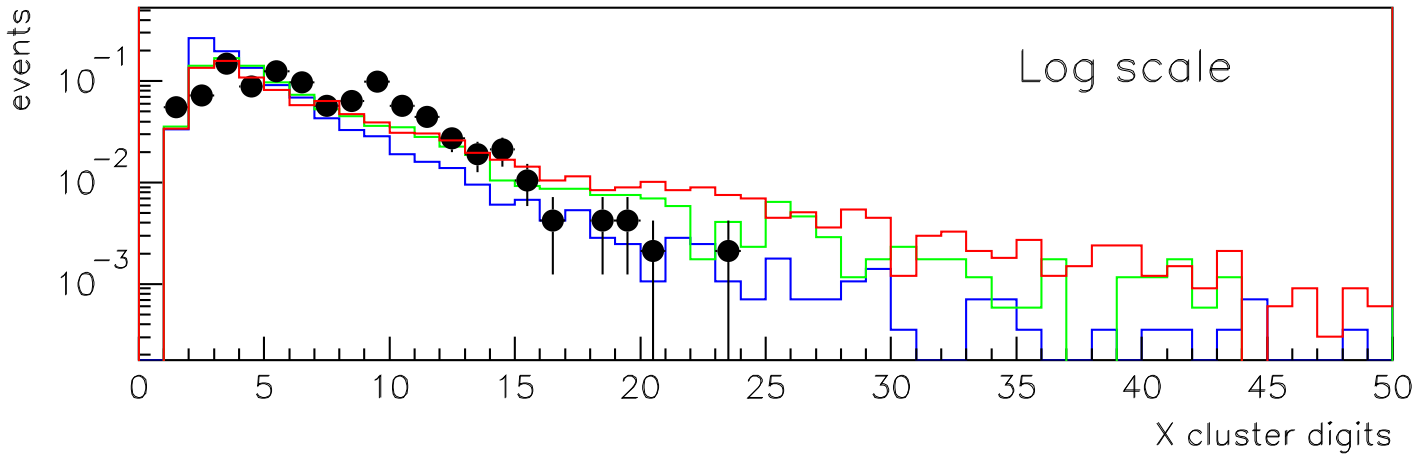
Cluster size, in Y (cont.)

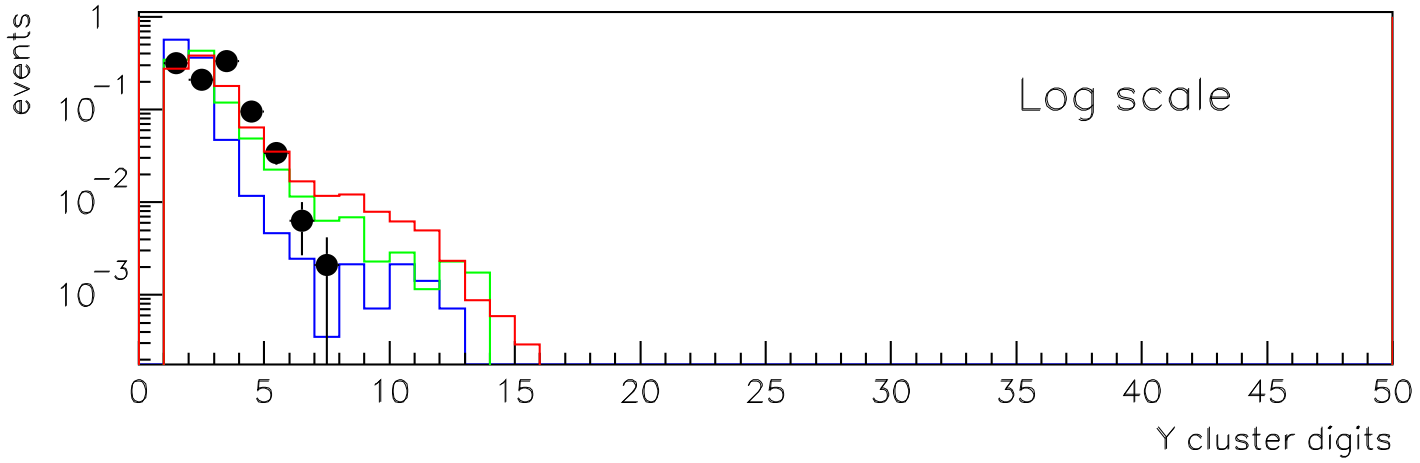


Cluster size, in X and Y

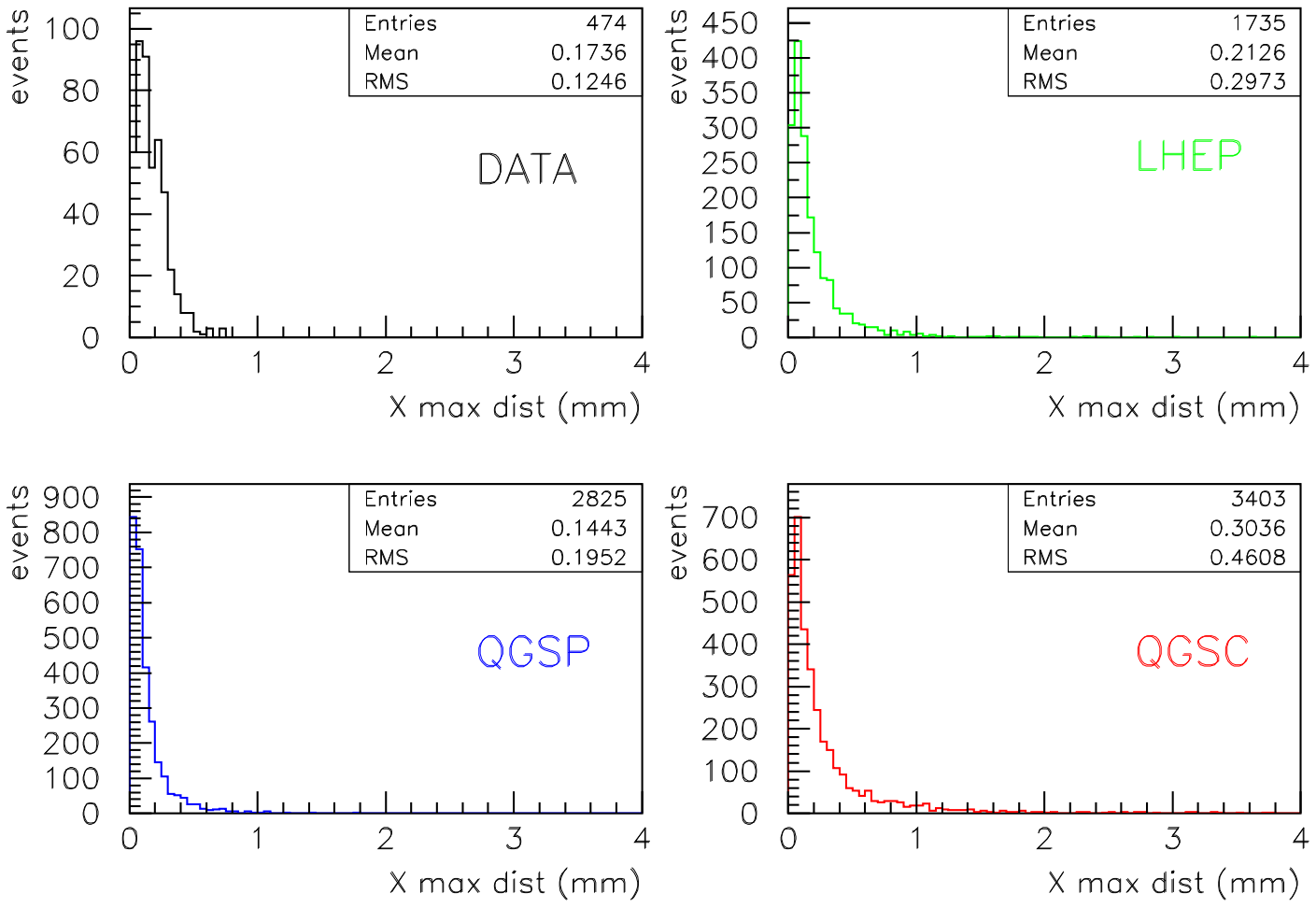


Cluster size, in X and Y (cont.)

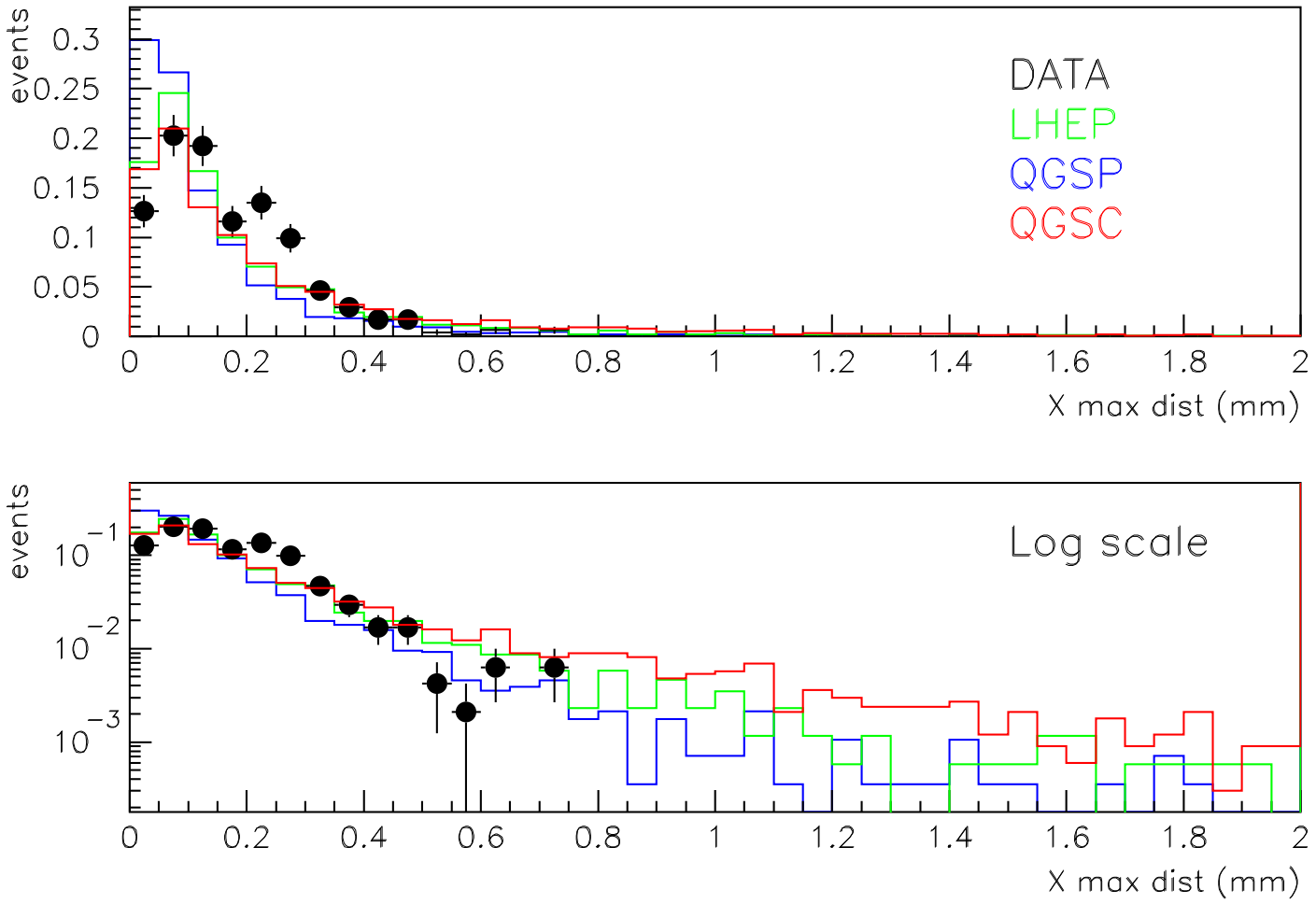




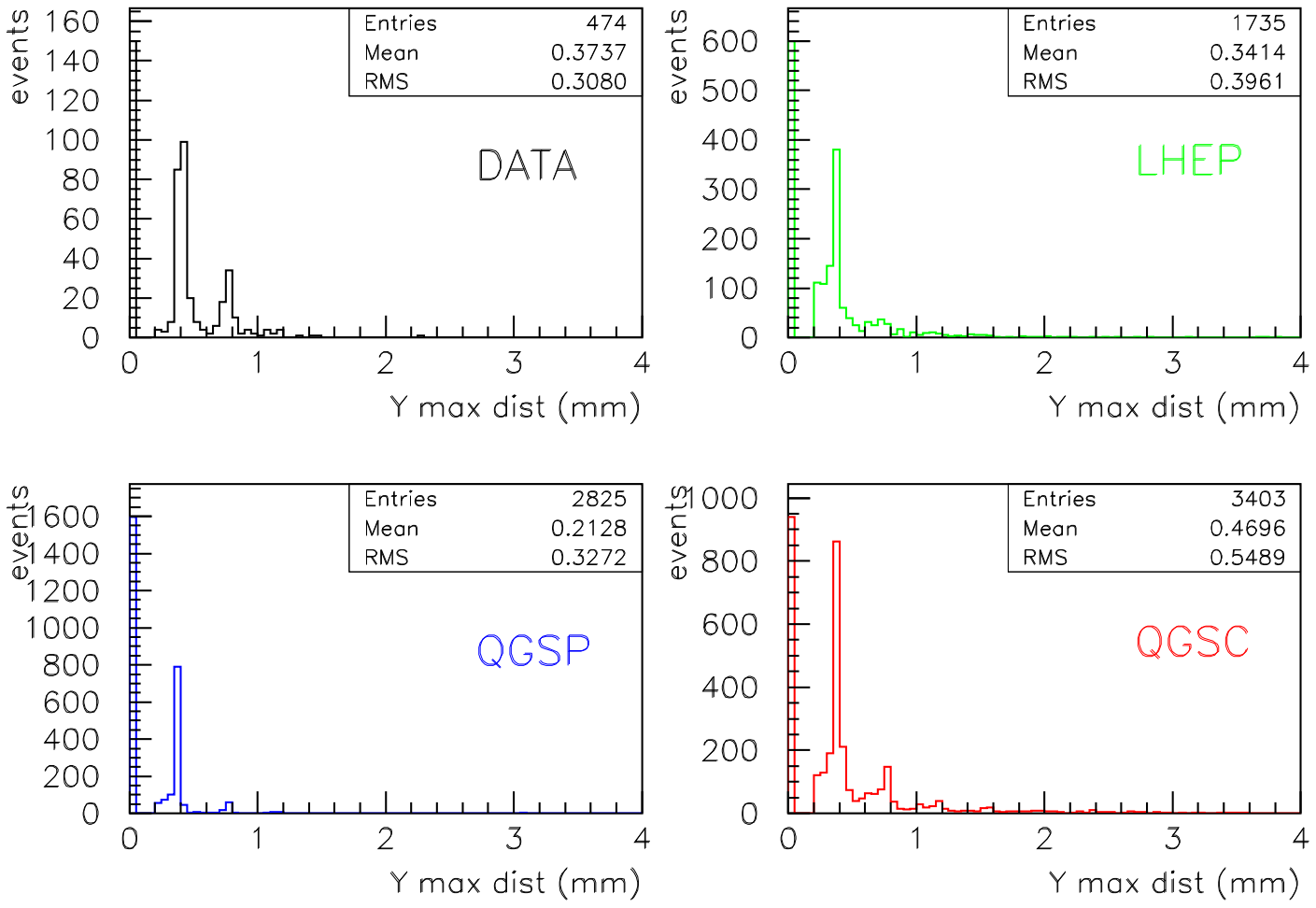
Max distance, in X



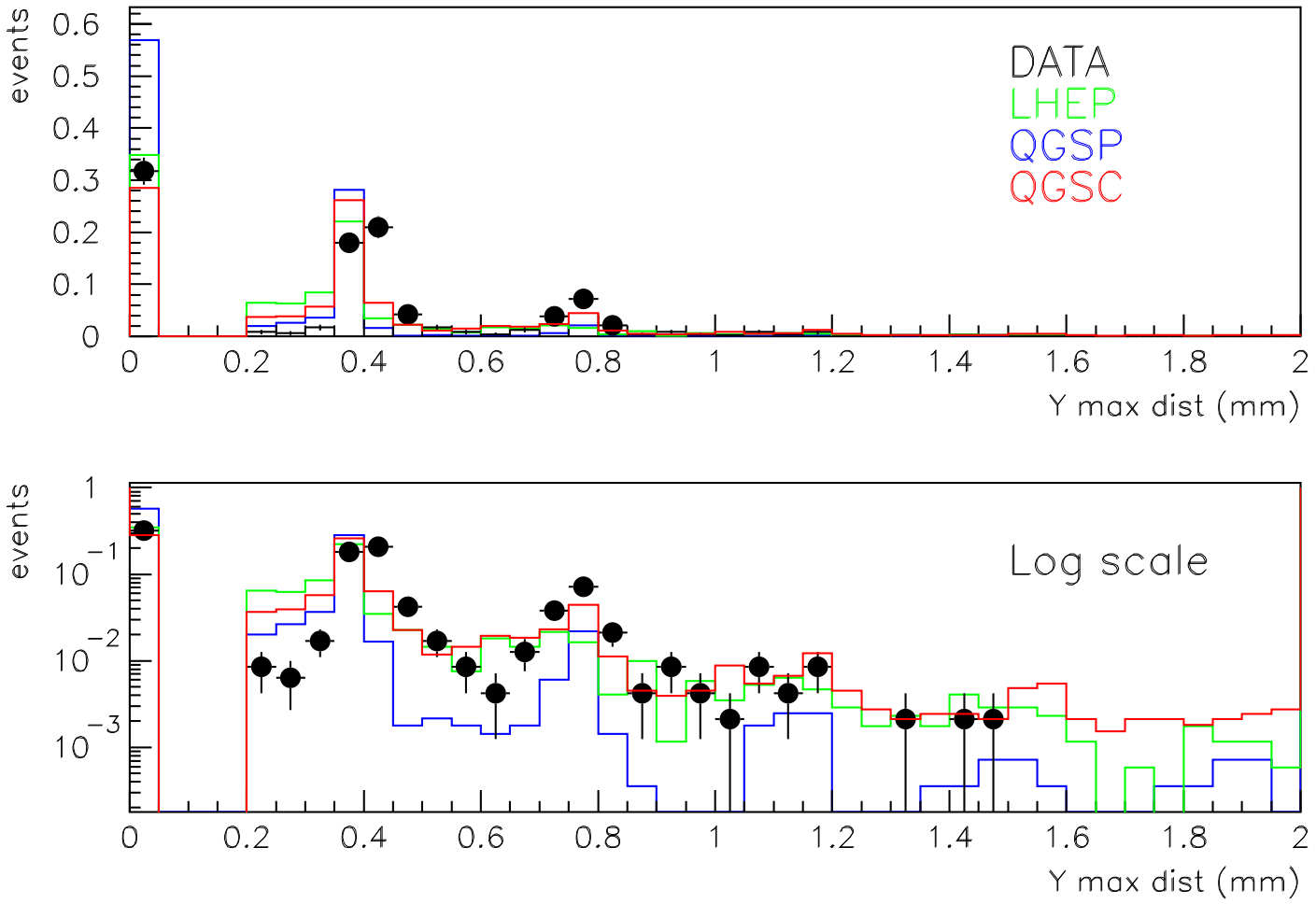
Max distance, in X (cont.)



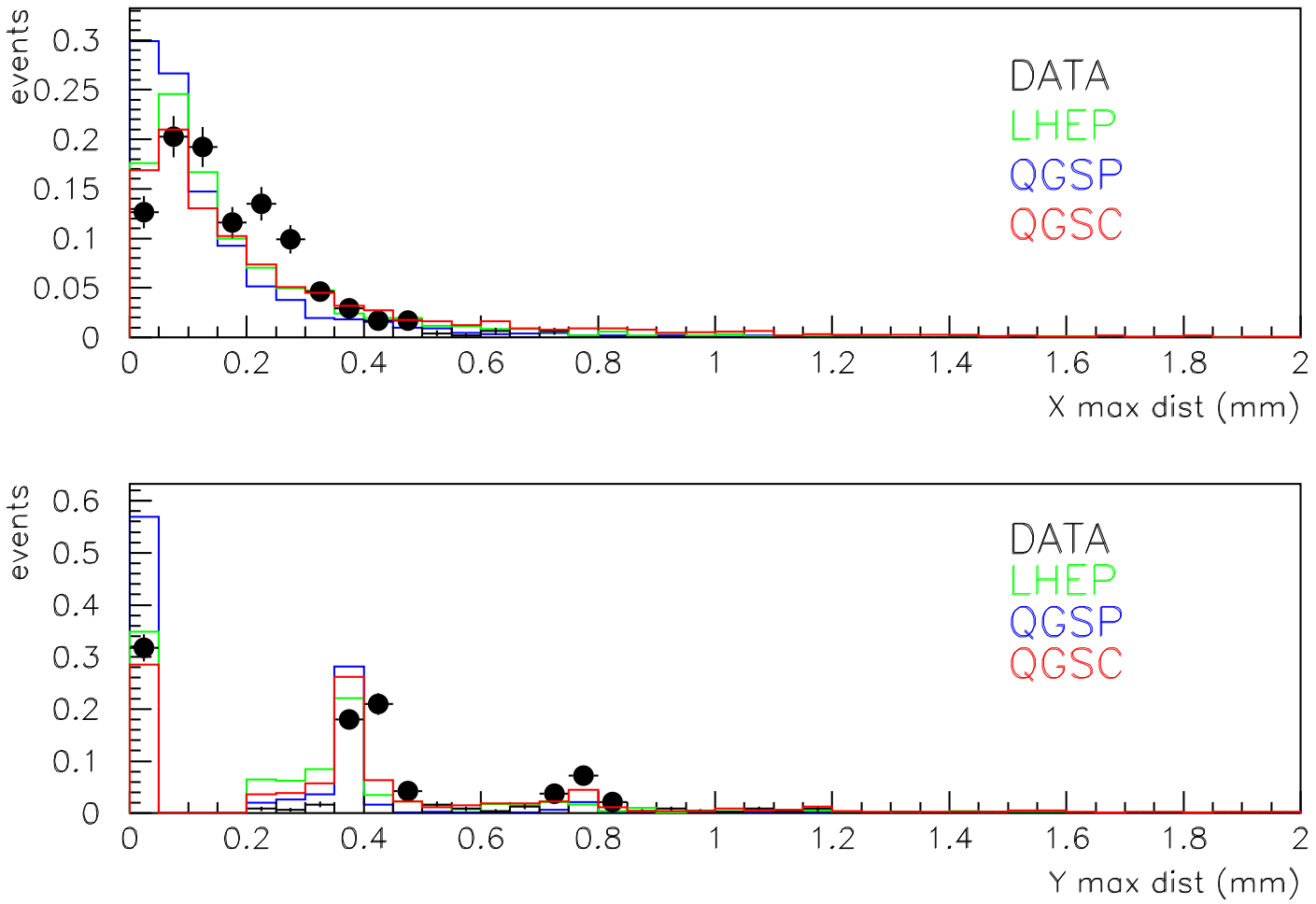
Max distance, in Y



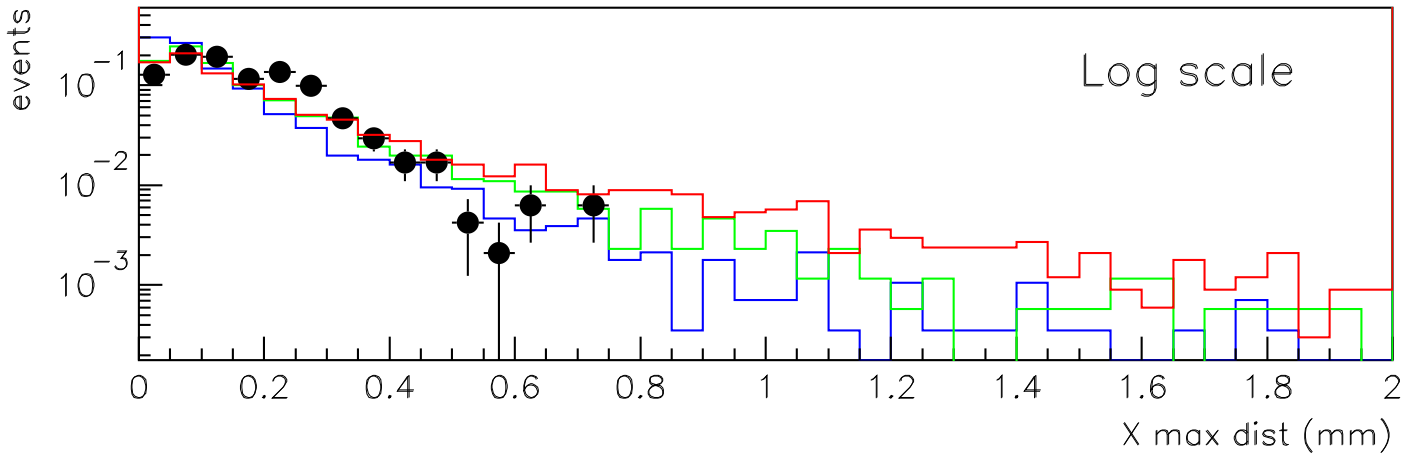
Max distance, in Y (cont.)

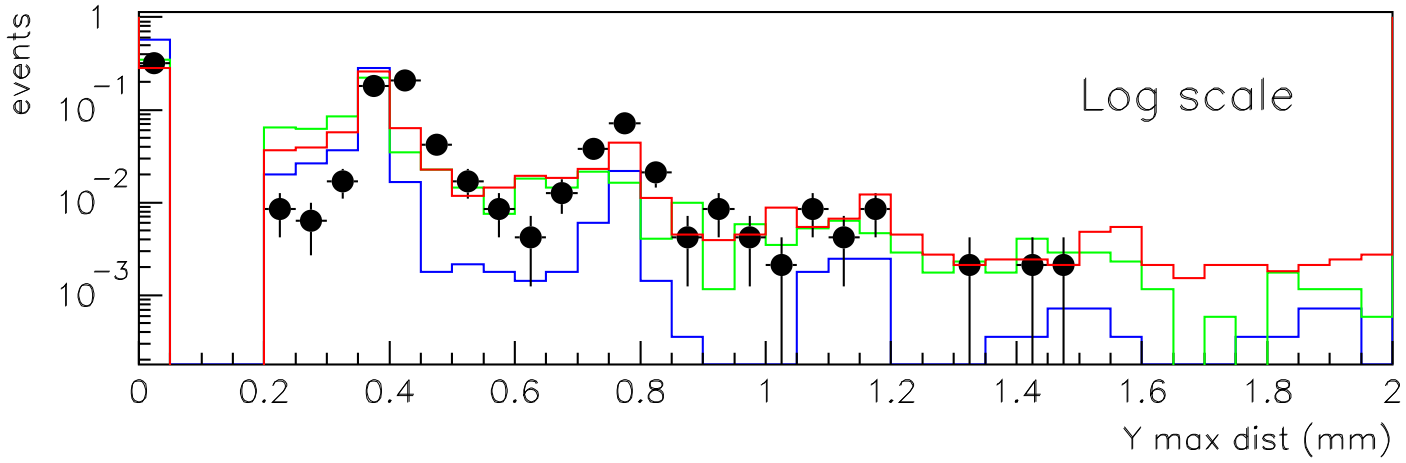


Max distance, in X and Y

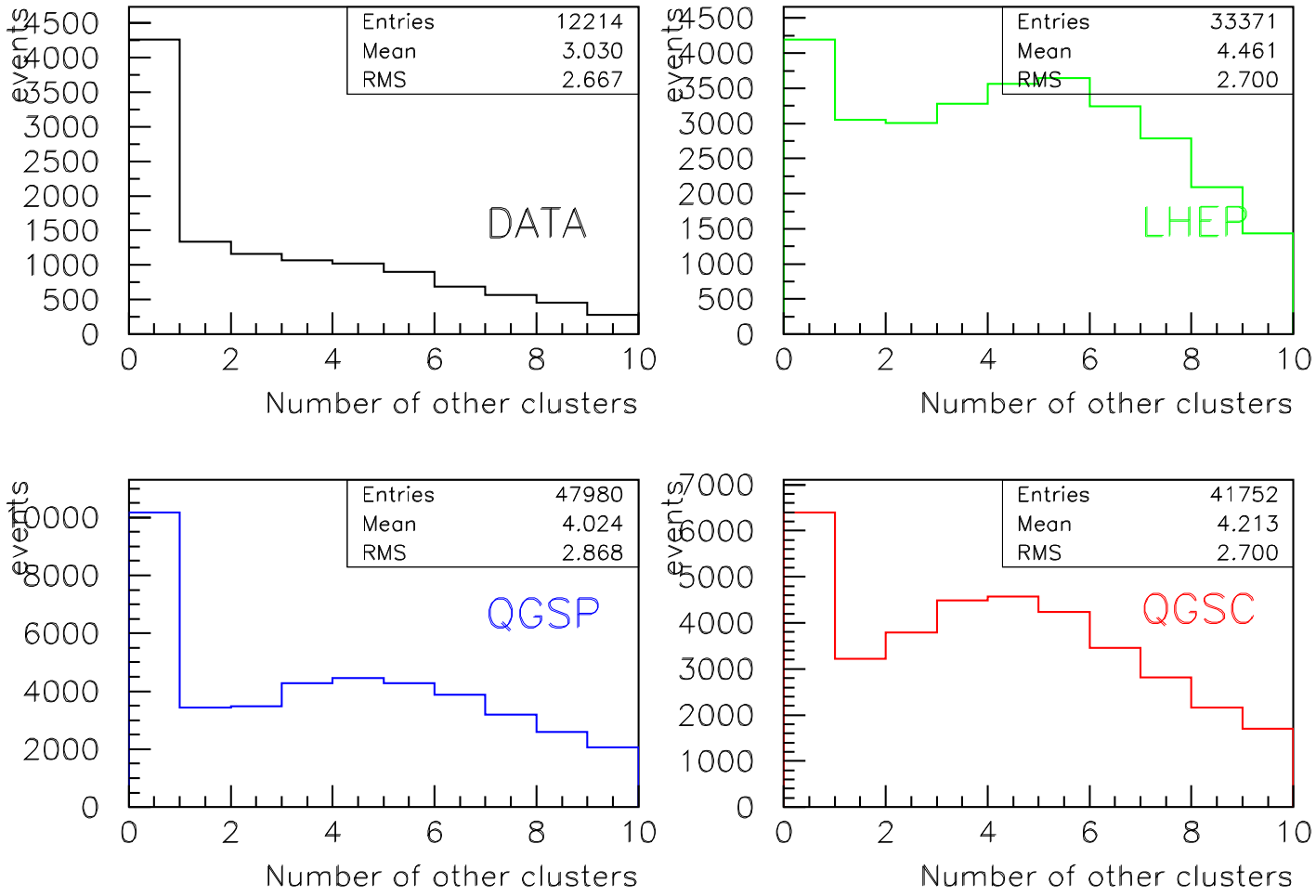


Max distance, in X and Y (cont.)

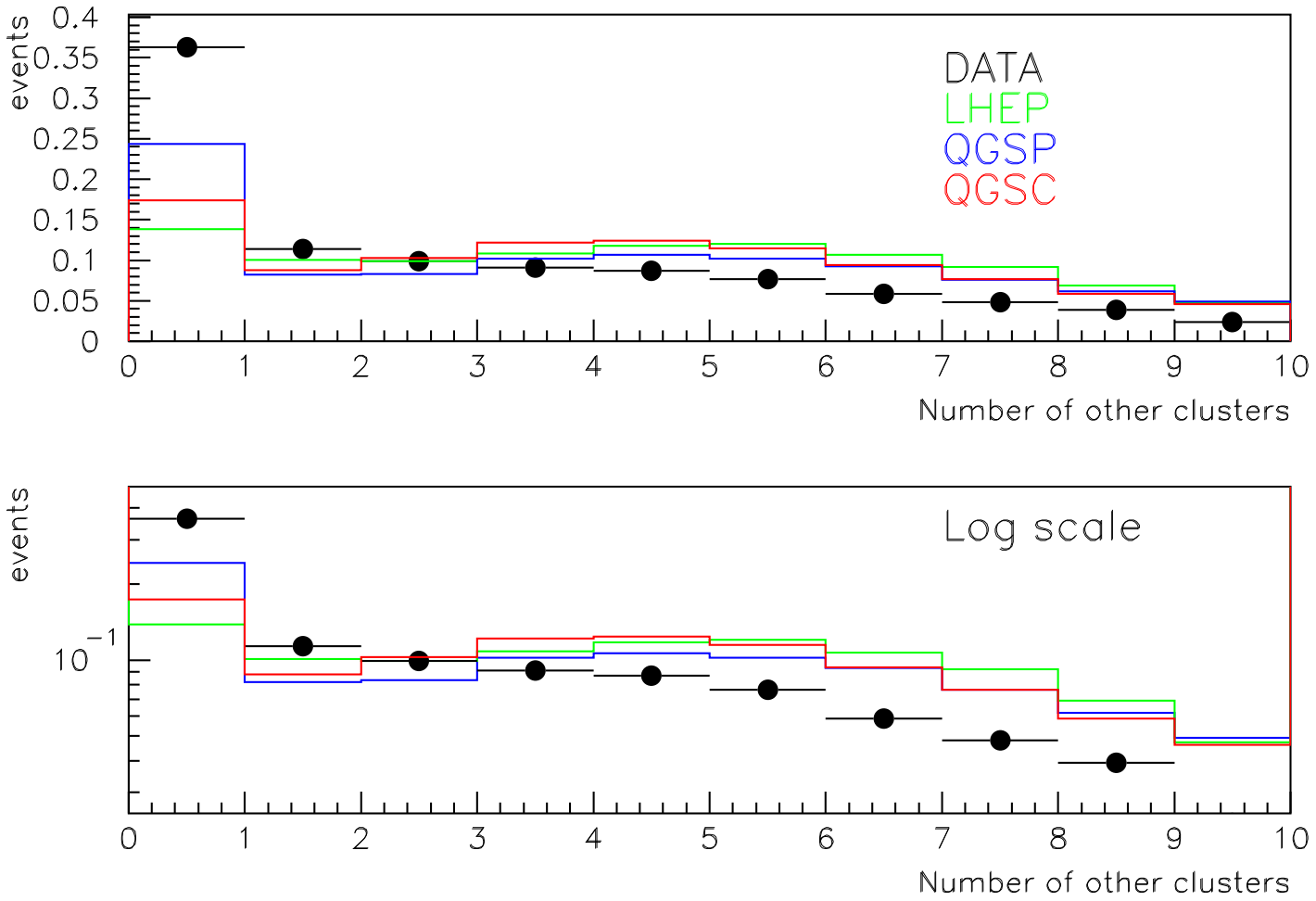




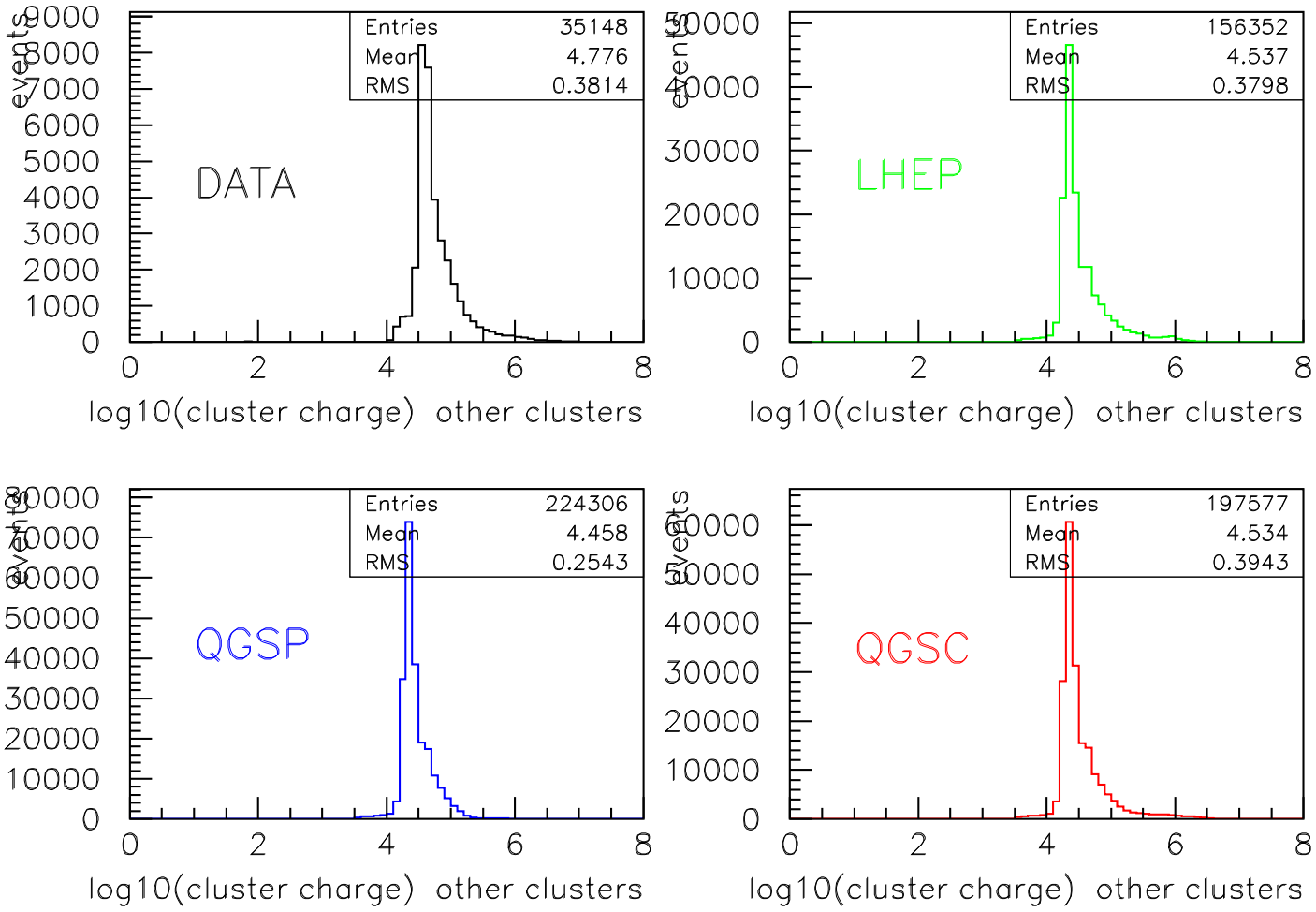
Number of Other Clusters



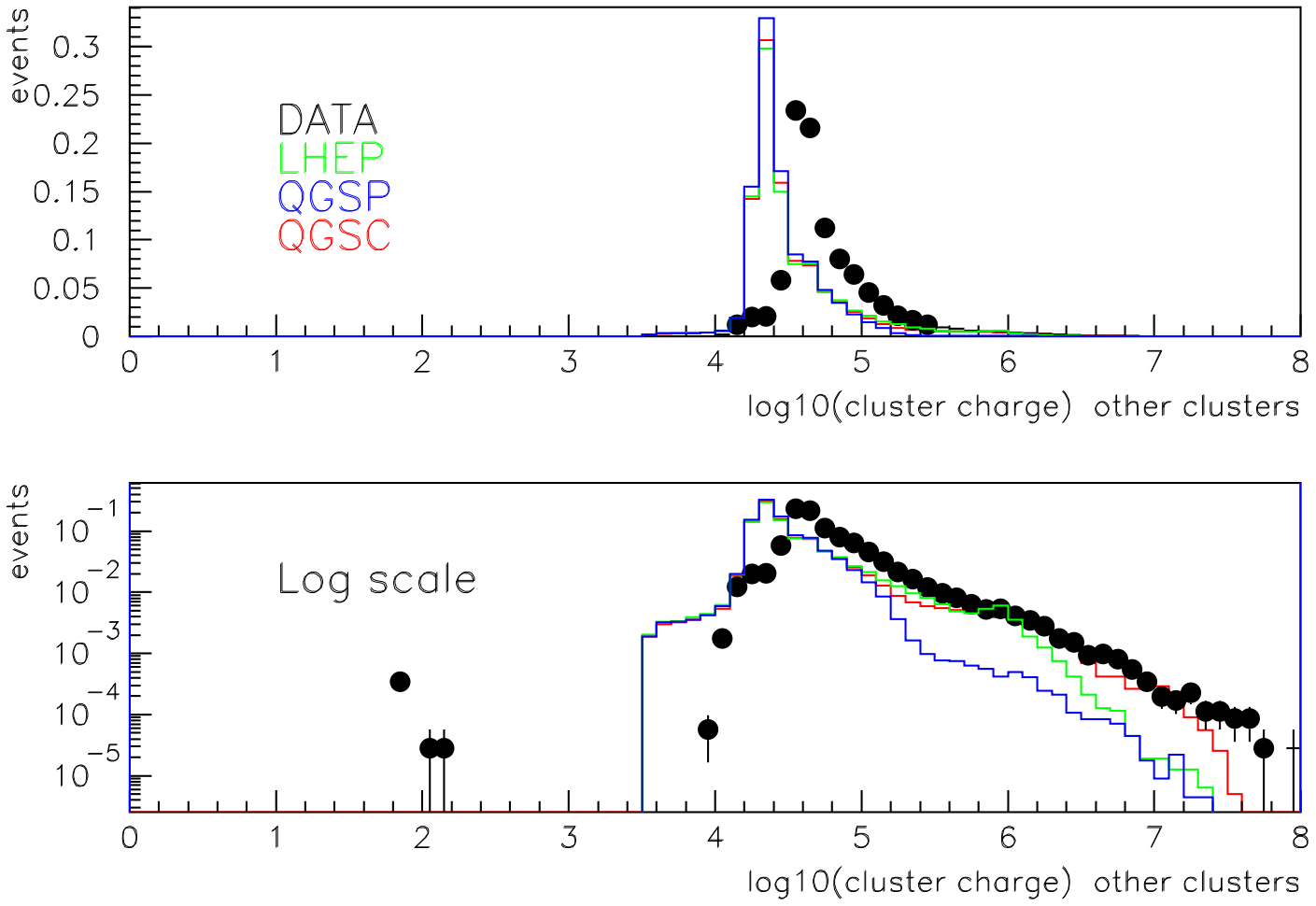
Number of Other Clusters (cont.)



Charge of Other Clusters

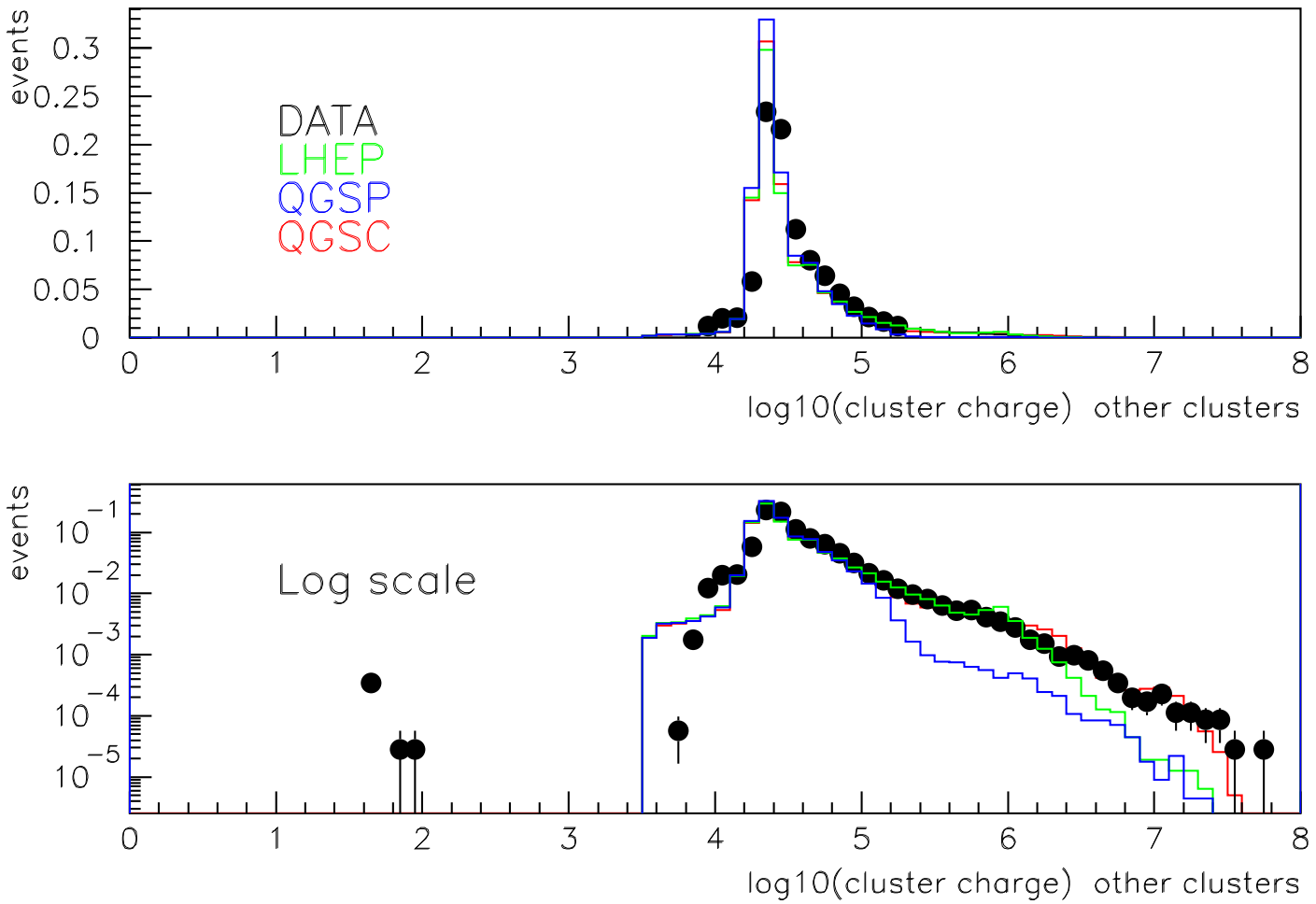


Charge of Other Clusters (cont.)

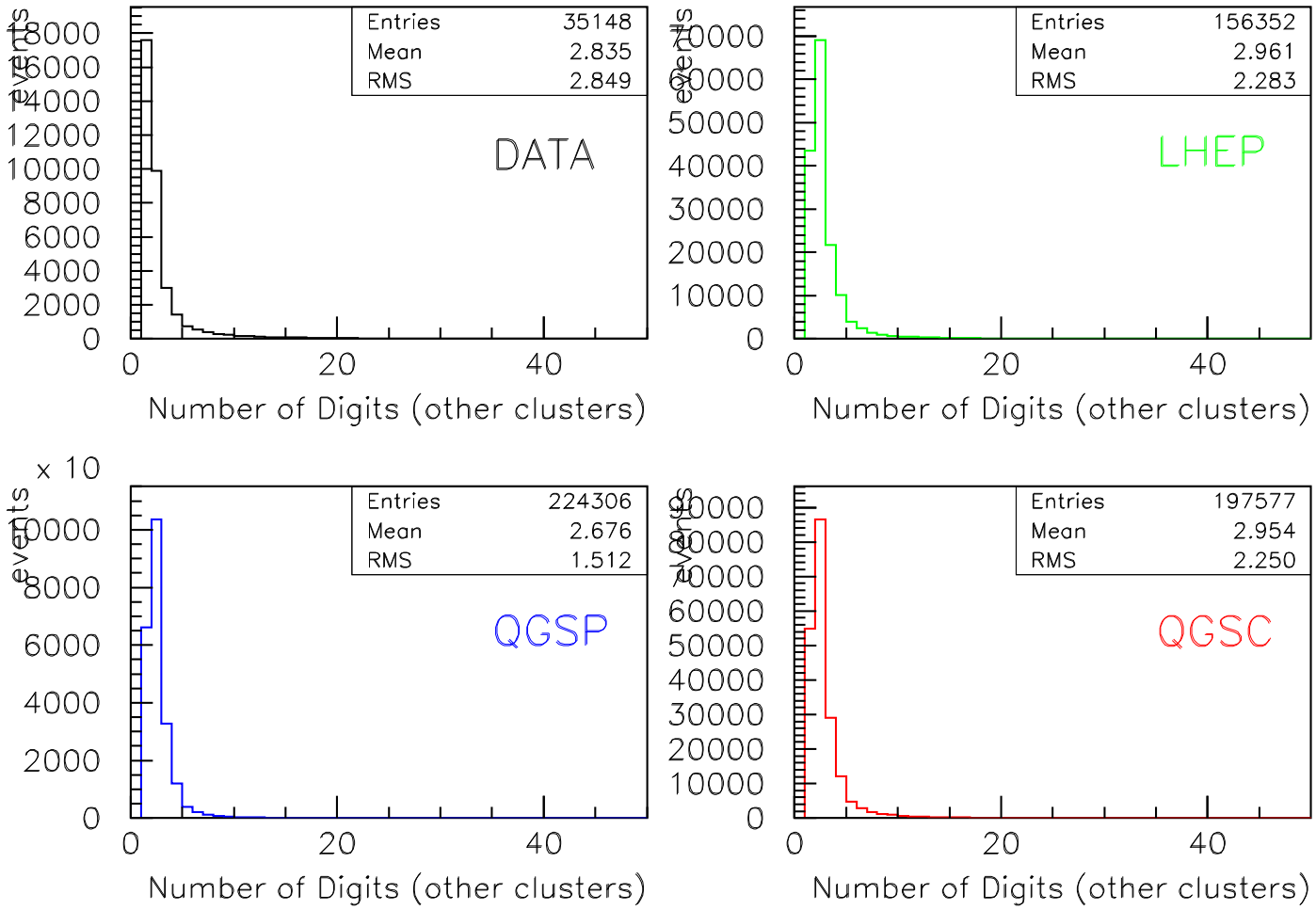


Shift in the Charge of Other Clusters

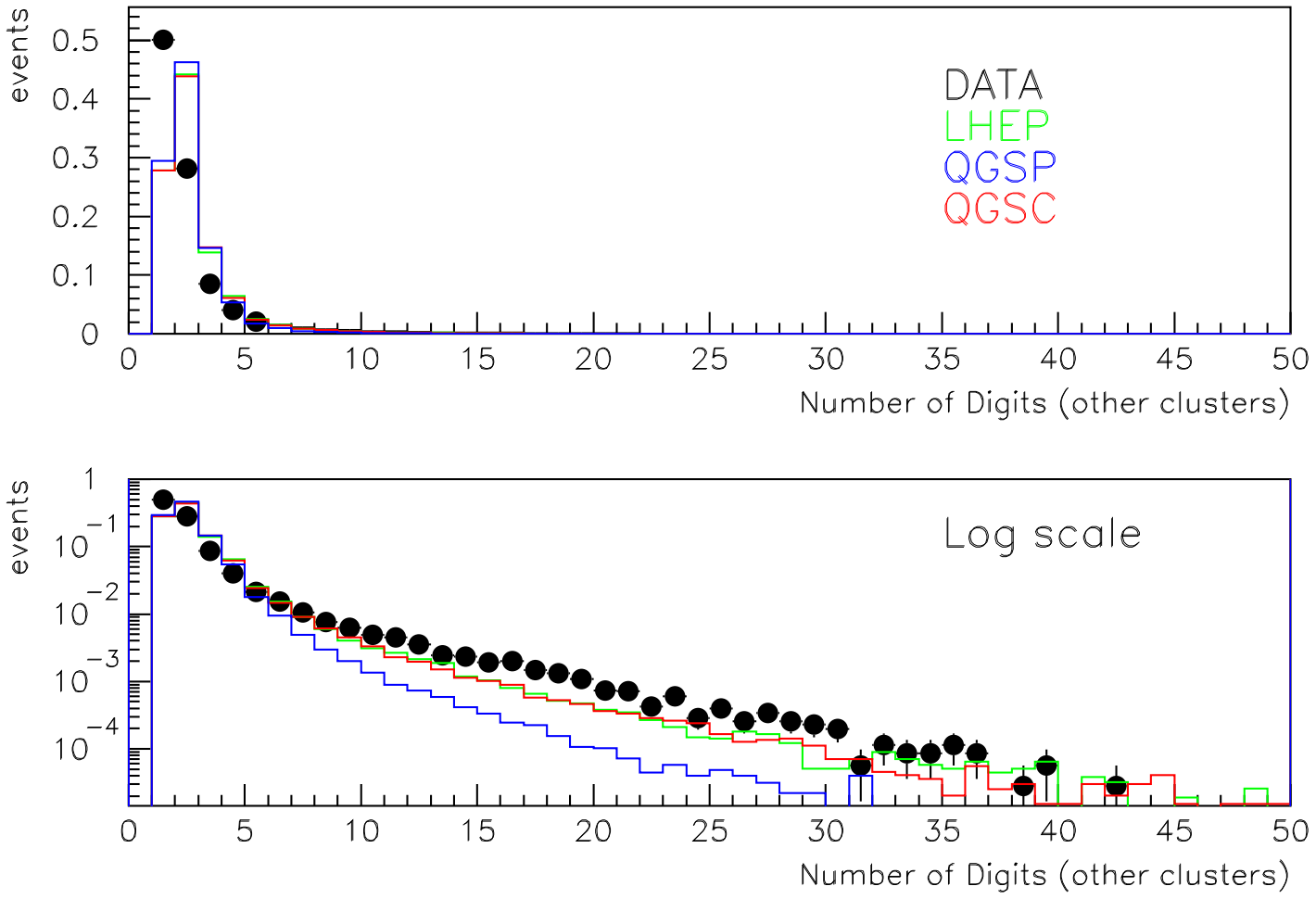
The shift corresponds to a factor data/sim of 2.00 .



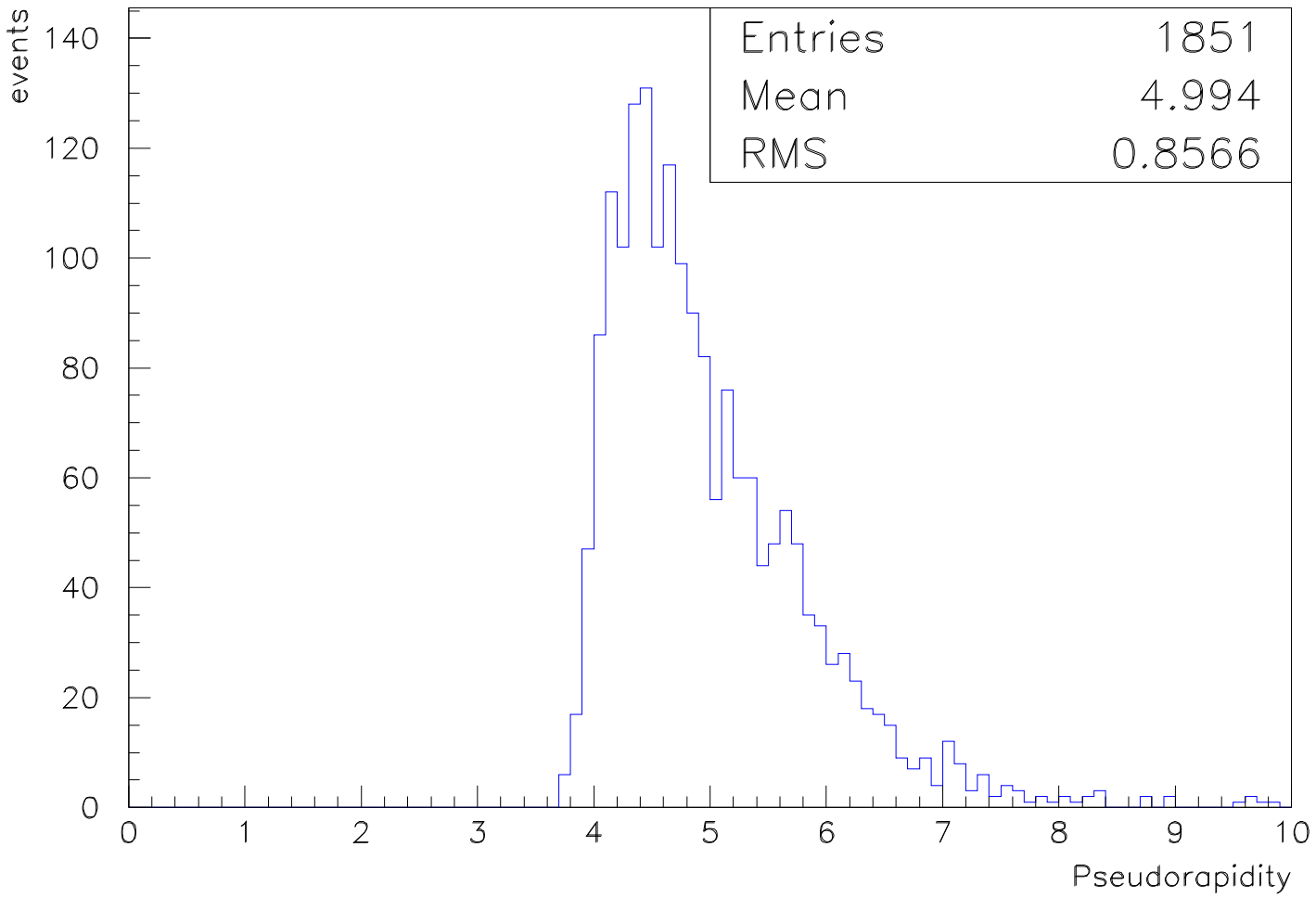
Cluster Size of Other Clusters



Cluster Size of Other Clusters (cont.)



Eta acceptance



Robustness of the results

The various cluster distributions seem quite "robust" with respect to the following changes:

- Shift in z in the analysis of real data.
- Change in the beam spot size $(1 \div 5\,mm)$.
- Change in the pixel clustering zero-suppression threshold.
- Change in the noise.

Furthermore, the events falling in the Emax/Eloss bin around 1 have many more wider clusters, which are anyhow dominated by a single pixel, than in the simulation.

Conclusions

The various cluster distributions are quite stable with respect to many changes. However, the energy calibration , which affects directly only few cluster distributions (Eloss, Emax), is quite unclear. If we assume that this issue does not affect the other distributions (the cluster structure: width, size, farther hit, etc.), then we can draw the following conclusions:

- Improvements from the old results (from Physics lists and beam composition).
- Theory-driven models in general (QGSP, QGSP_BIC, FTFP) are better than the parametrized one (LHEP).
- Reasonable but not yet very good agreement of theory-driven models with data.
- Need of tuning QGSP (QGSP_BIC and FTFP as well) with the data. QGSC has some problem to be fixed.