Ionization process simulation in gas

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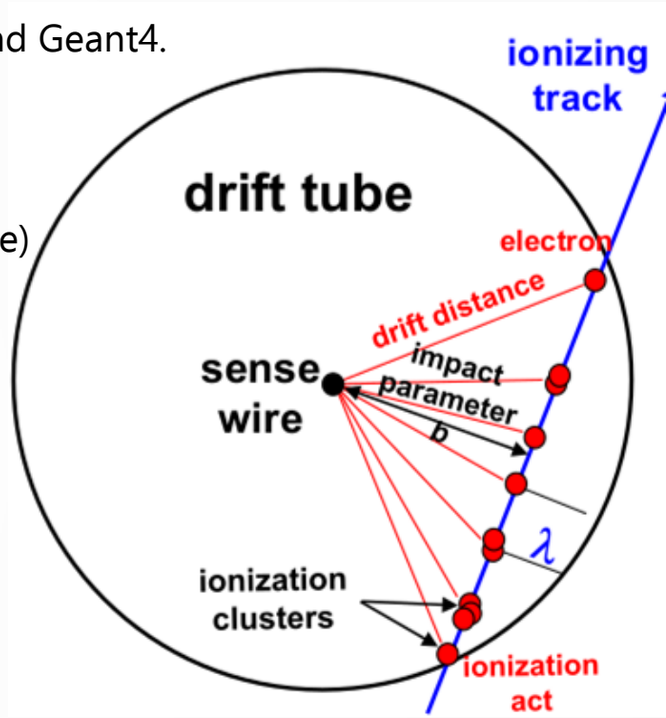
Goal : Simulation/parametrization of ionization cluster generation in Geant4

To investigate the potential of the Cluster Counting technique (for He based drift chamber) on physics events a reasonable simulation/parametrization of the ionization clusters generation in geant4 is needed.

We are investigating about the ionization losses of different particles in He-iC_4H_{10} using Garfield++ and Geant4.



Garfield++ :
- **(Heed)** simulates the ionization process in the gasses (not only) in a detailed way.
- **(Magboltz)** computes the gas properties (drift and diffusion coefficients as function of the fields value)
- solves the electrostatic planar configuration and simulates the free charges movements and collections on the electrodes.

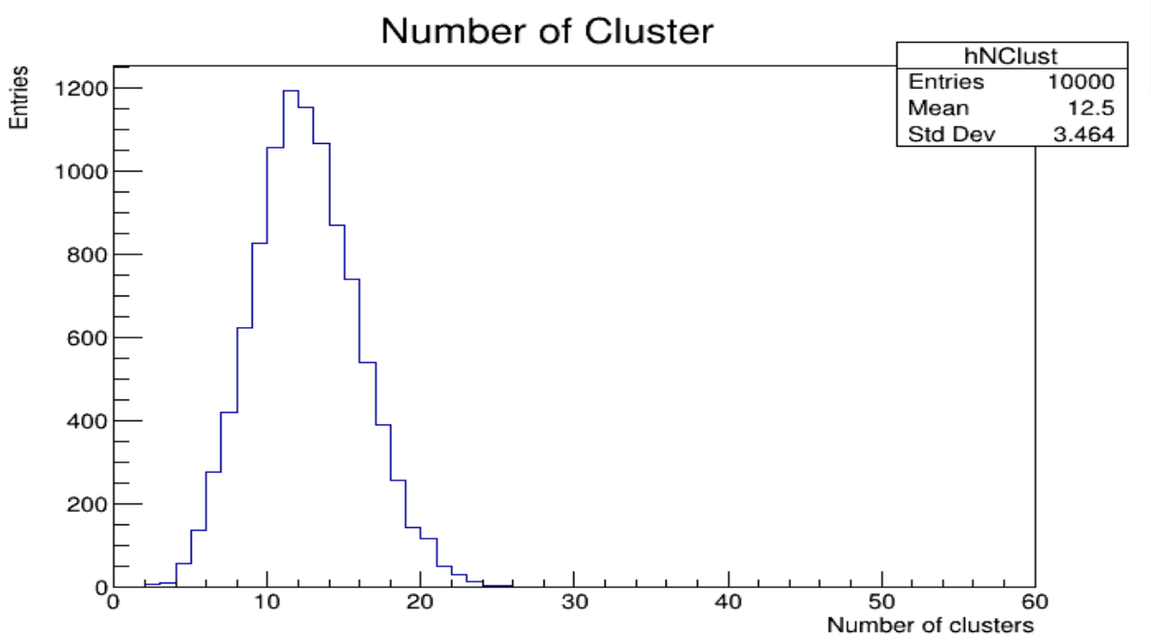
So Garfield can study and characterize the properties and performance of single cell or drift chamber with simple geometry, but cannot simulate a full detector neither study collider events.

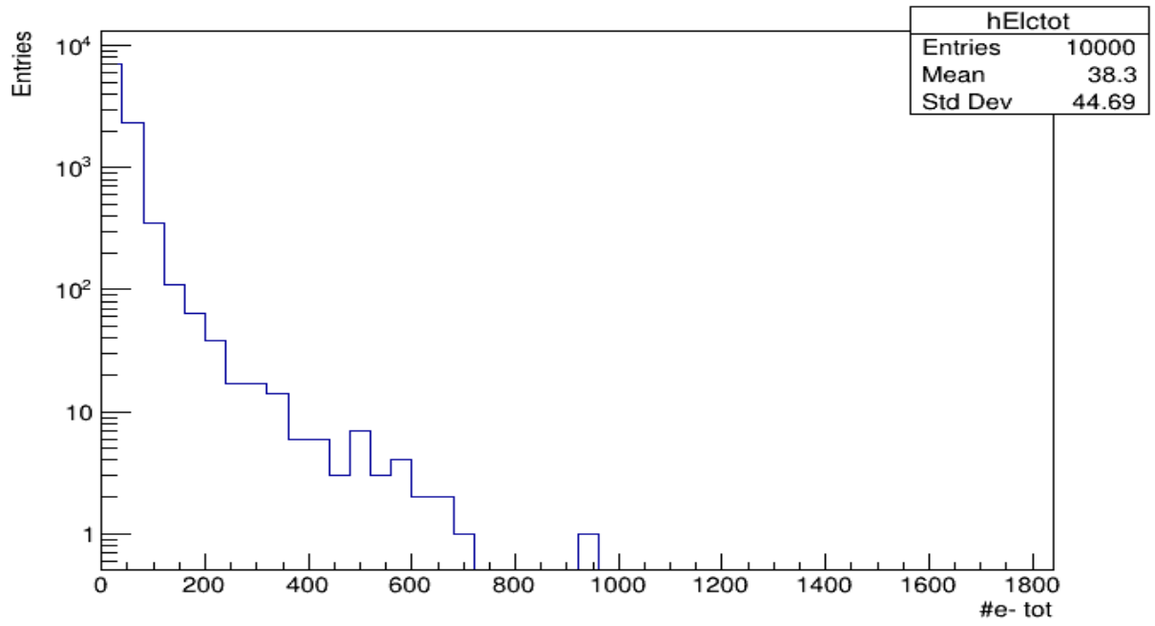
Geant4 :
- Simulates the elementary particle interaction with material of a full detector.
- Studies colliders events

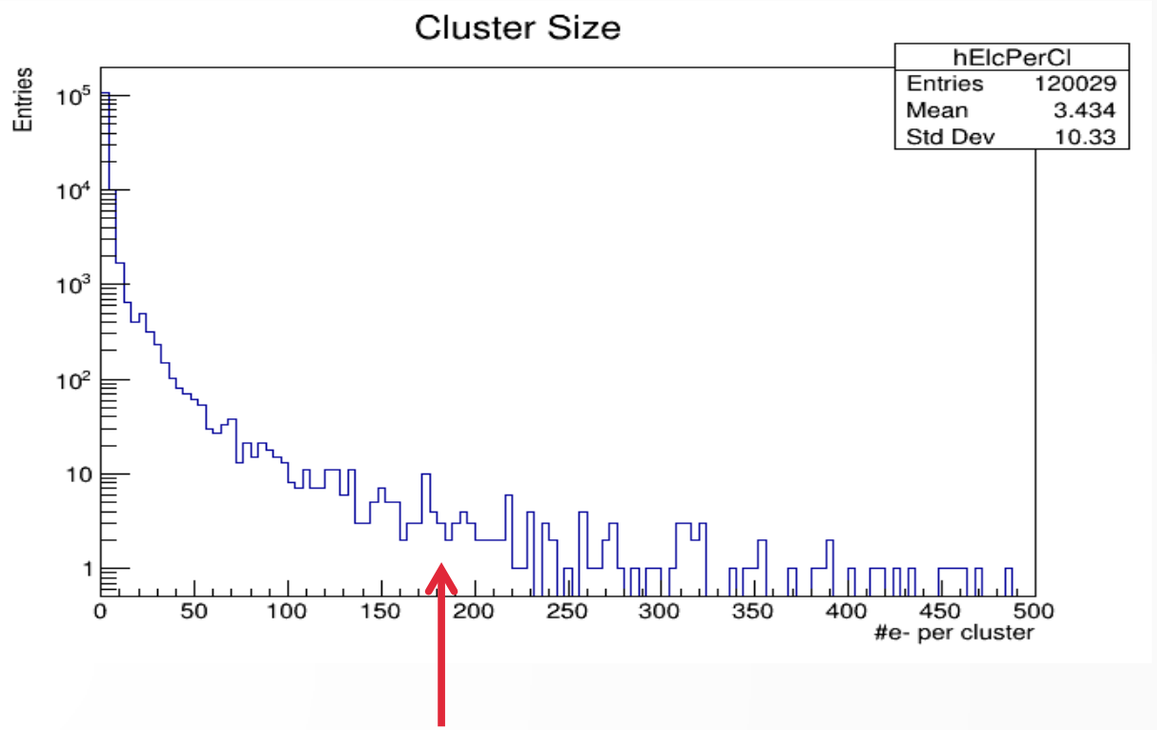
But...the fundamental properties and performance of the sensible elements (drift cells) have to be parameterized or ad-hoc physics models have to be defined.

Actually we are simulating a box of gas (90% He and 10% iC_4H_{10}) 1cmx1cmx1cm in which several particles pass through with Garfield++ and Geant4.

Garfield++ (Version 2019.3): mu- p=300MeV

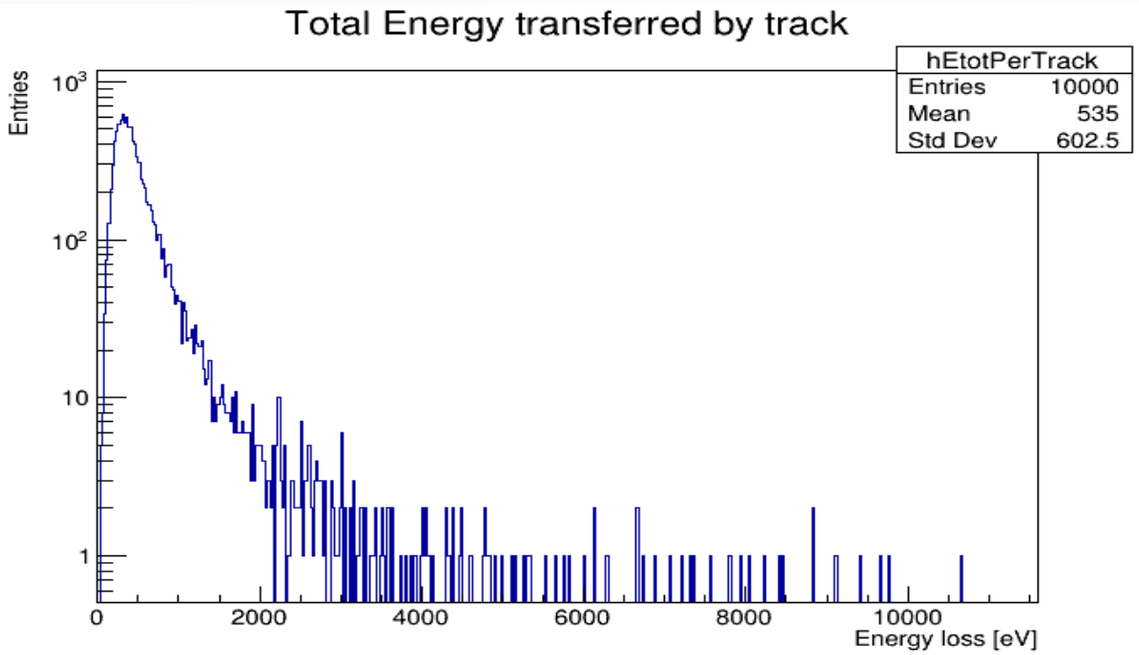




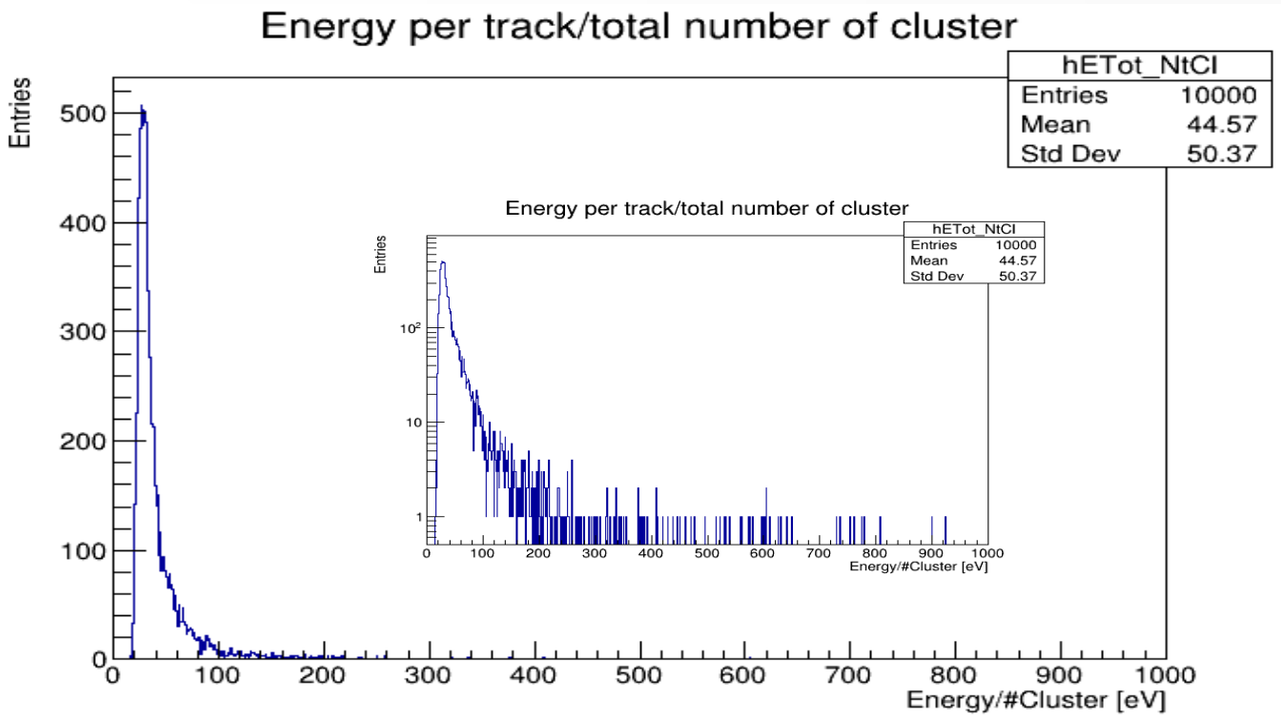


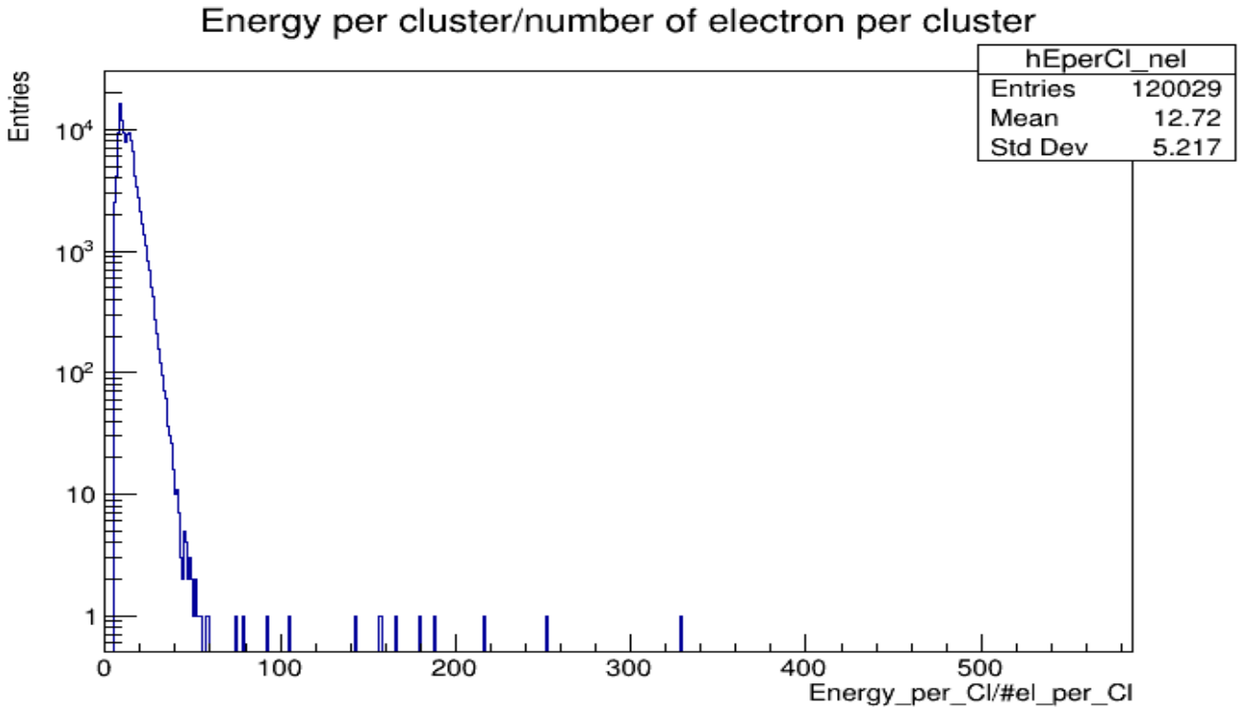
Some clusters present a really large cluster size!
In this case, delta rays contribution is prevailing.

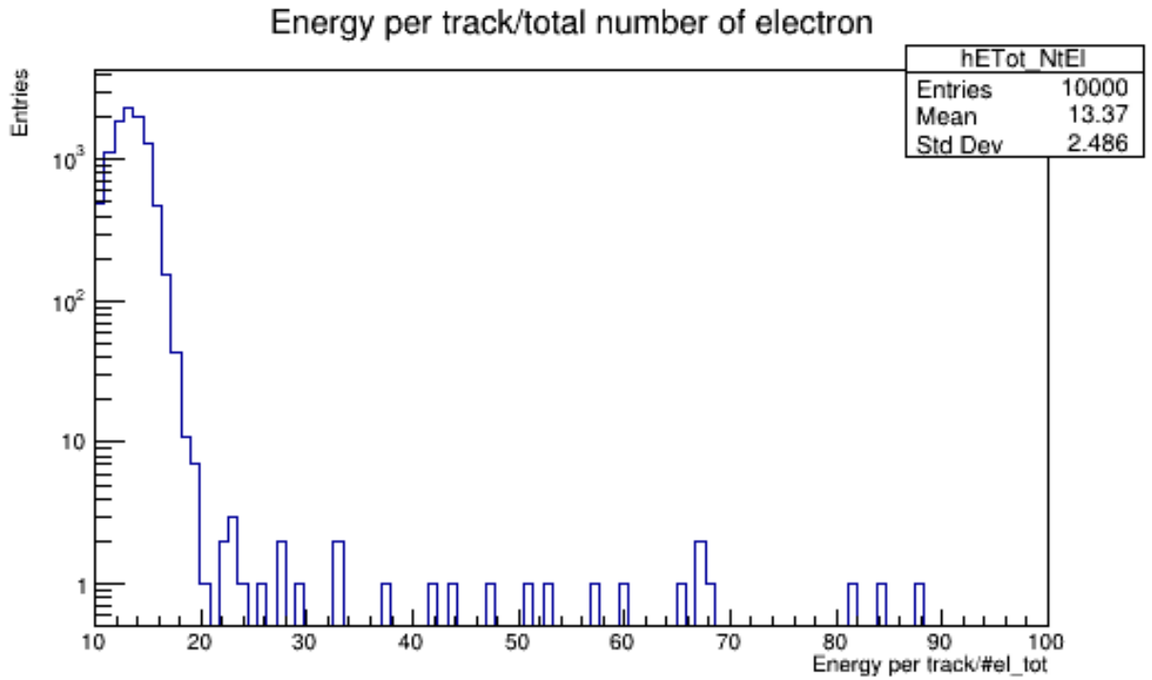
Note: During the simulation, the *DeltaElectronTransport* is enabled.

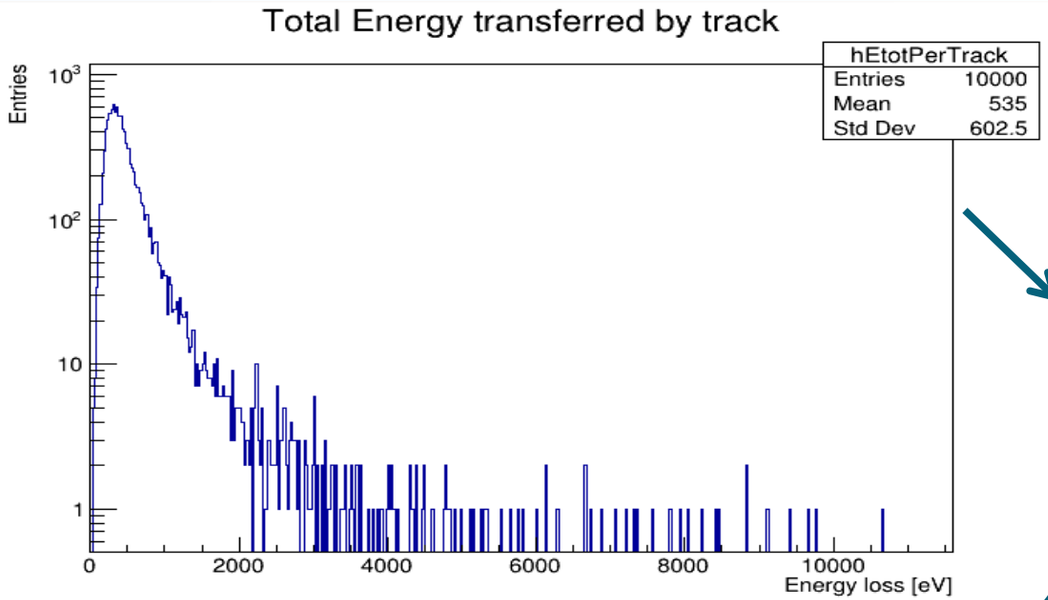


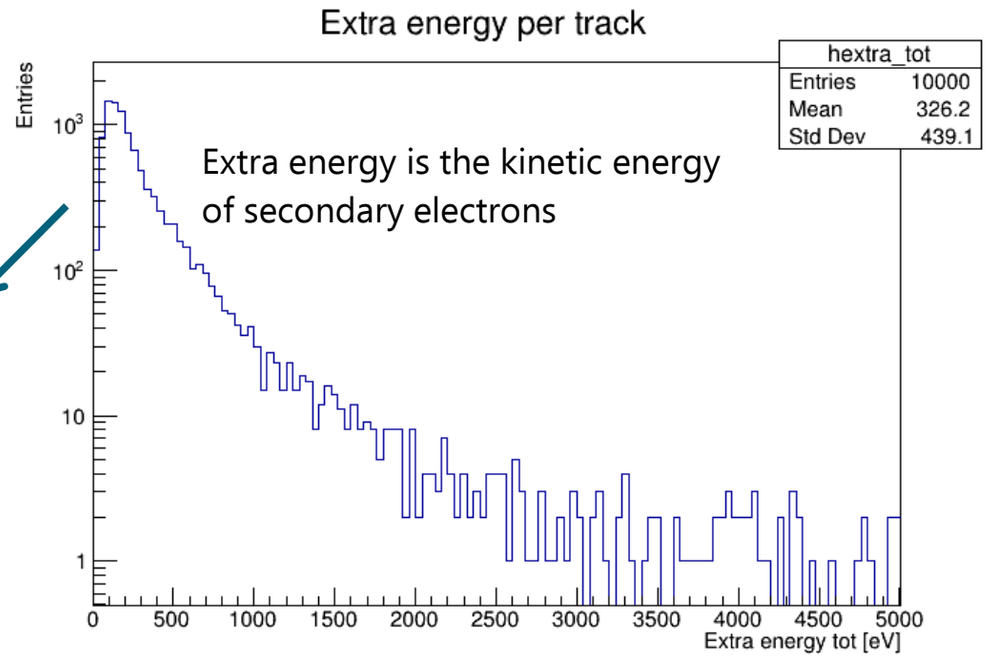
So to investigate the behavior of electron production, we studied the energy losses.



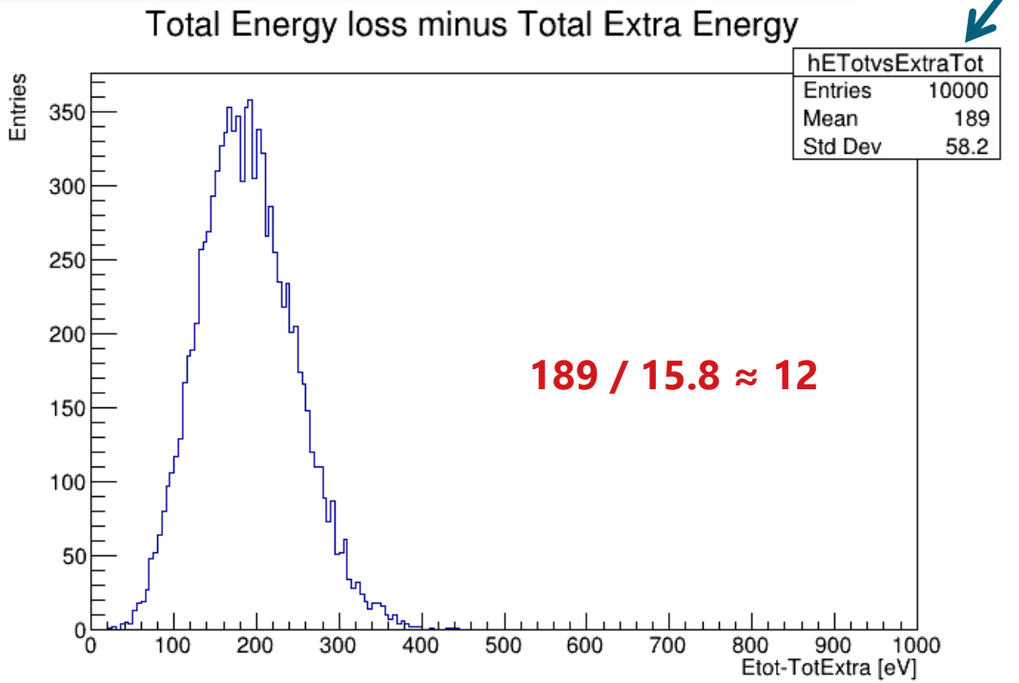

Energy per cluster/number of electron per cluster
hEperCl_nel
Entries 120029
Mean 12.72
Std Dev 5.217
Entries
Energy_per_Cl/#el_per_Cl

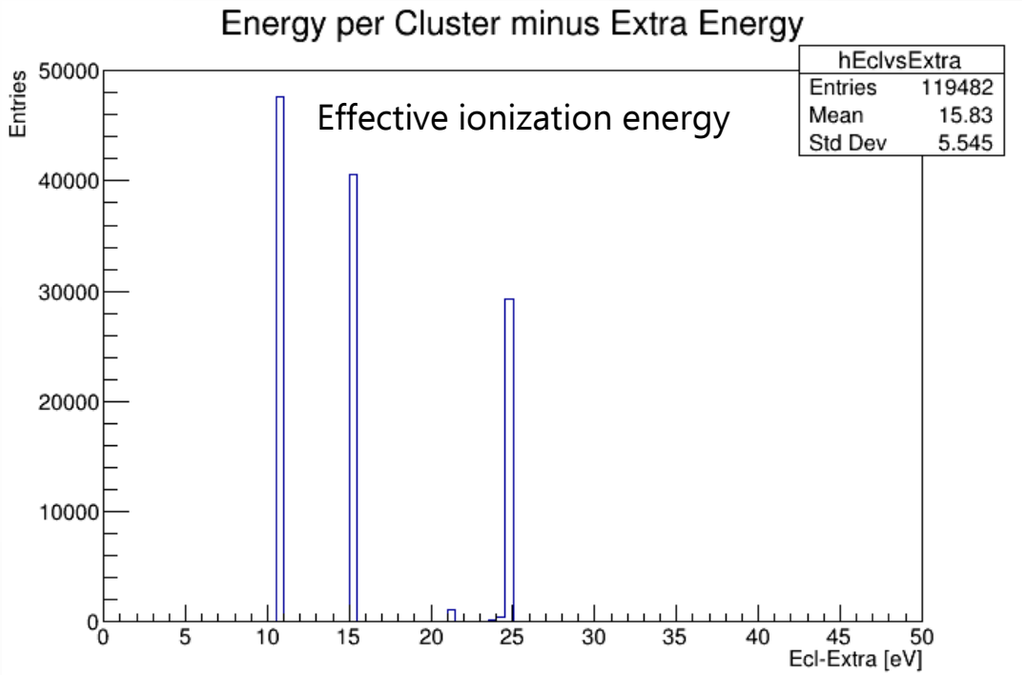

Energy per track/total number of electron
hETot_NtEl
Entries 10000
Mean 13.37
Std Dev 2.486
Entries
Energy per track/#el_tot

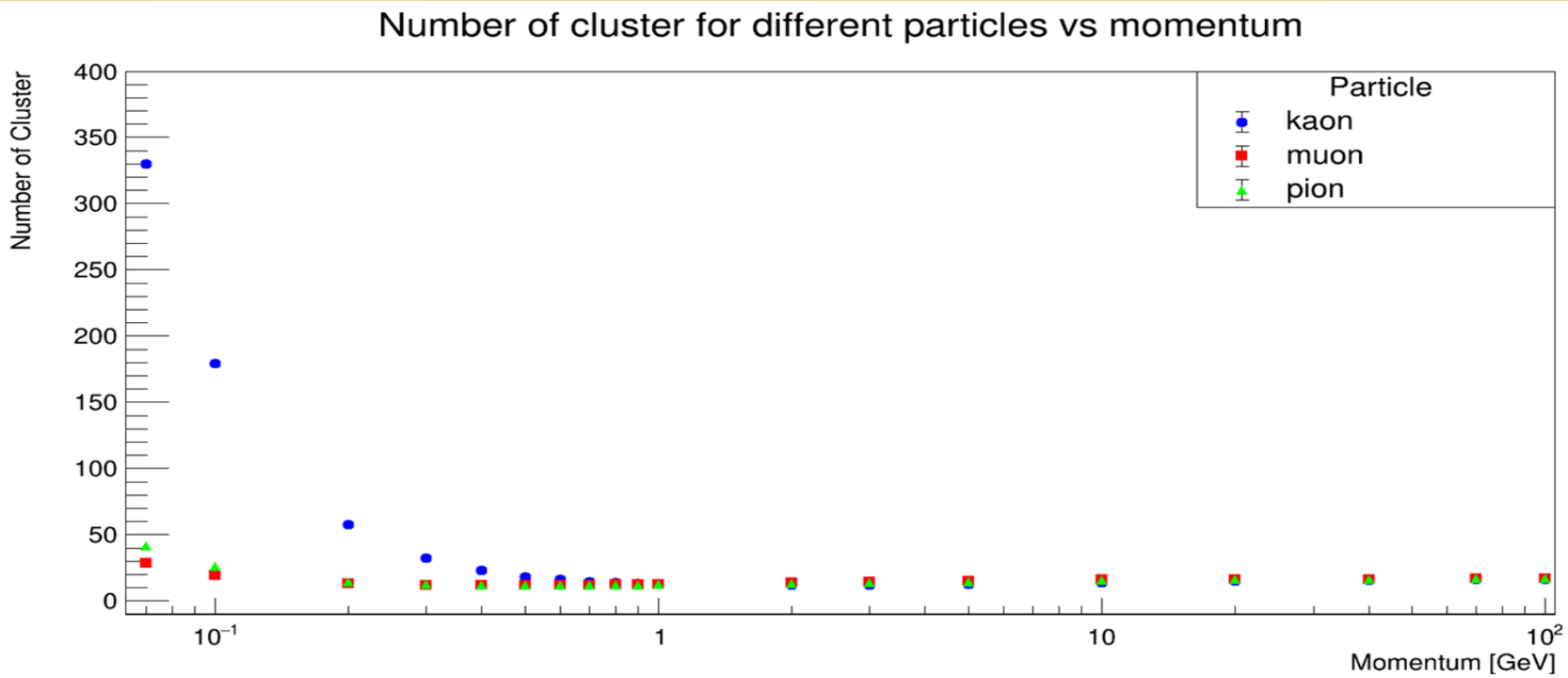


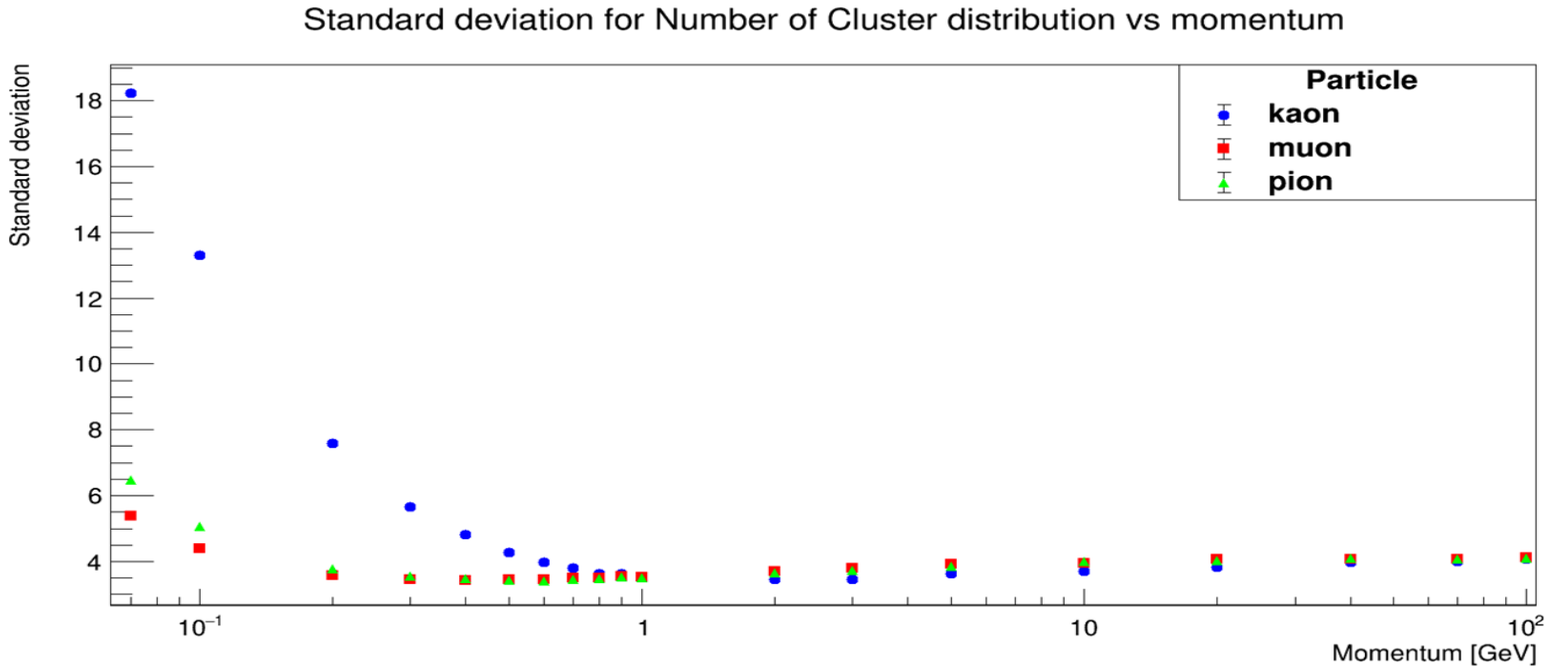


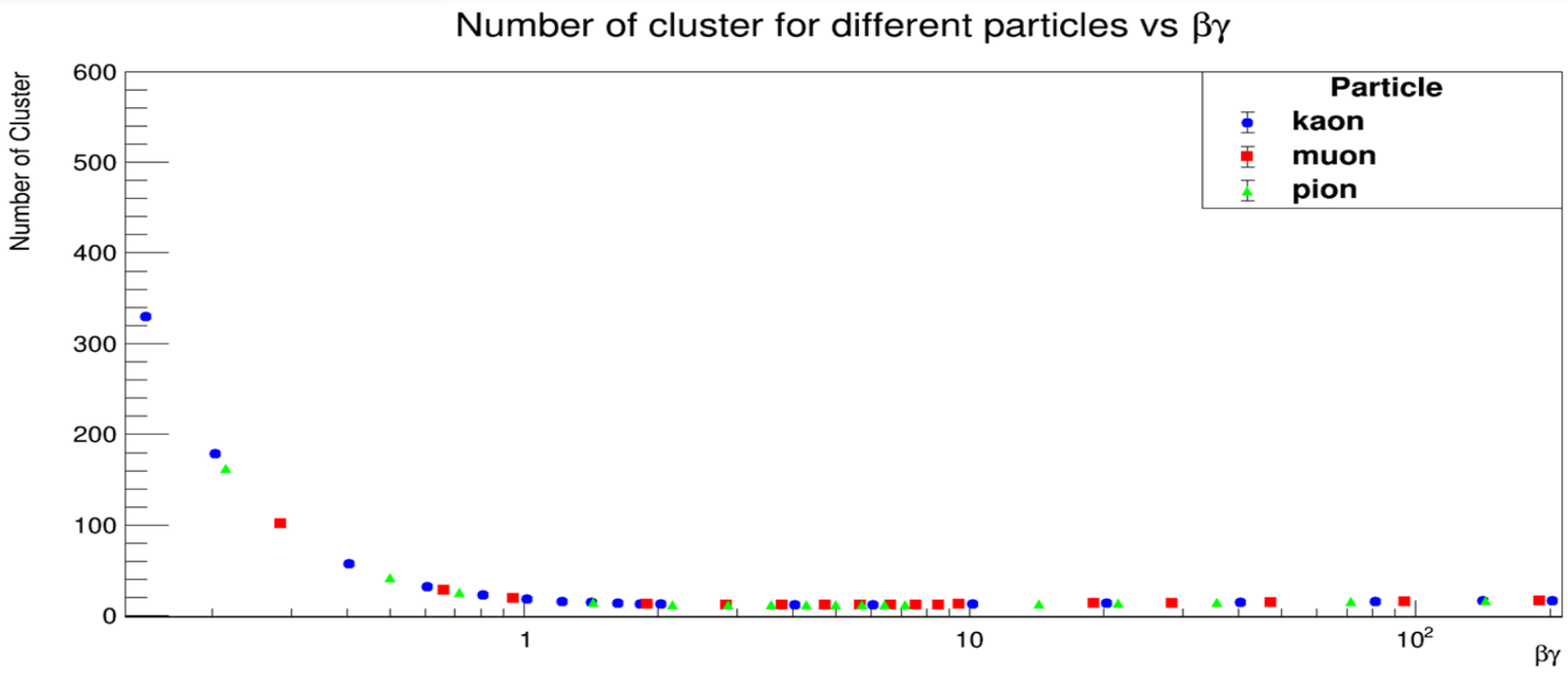
Subtracting "Extra energy" from "Total Energy", we obtain

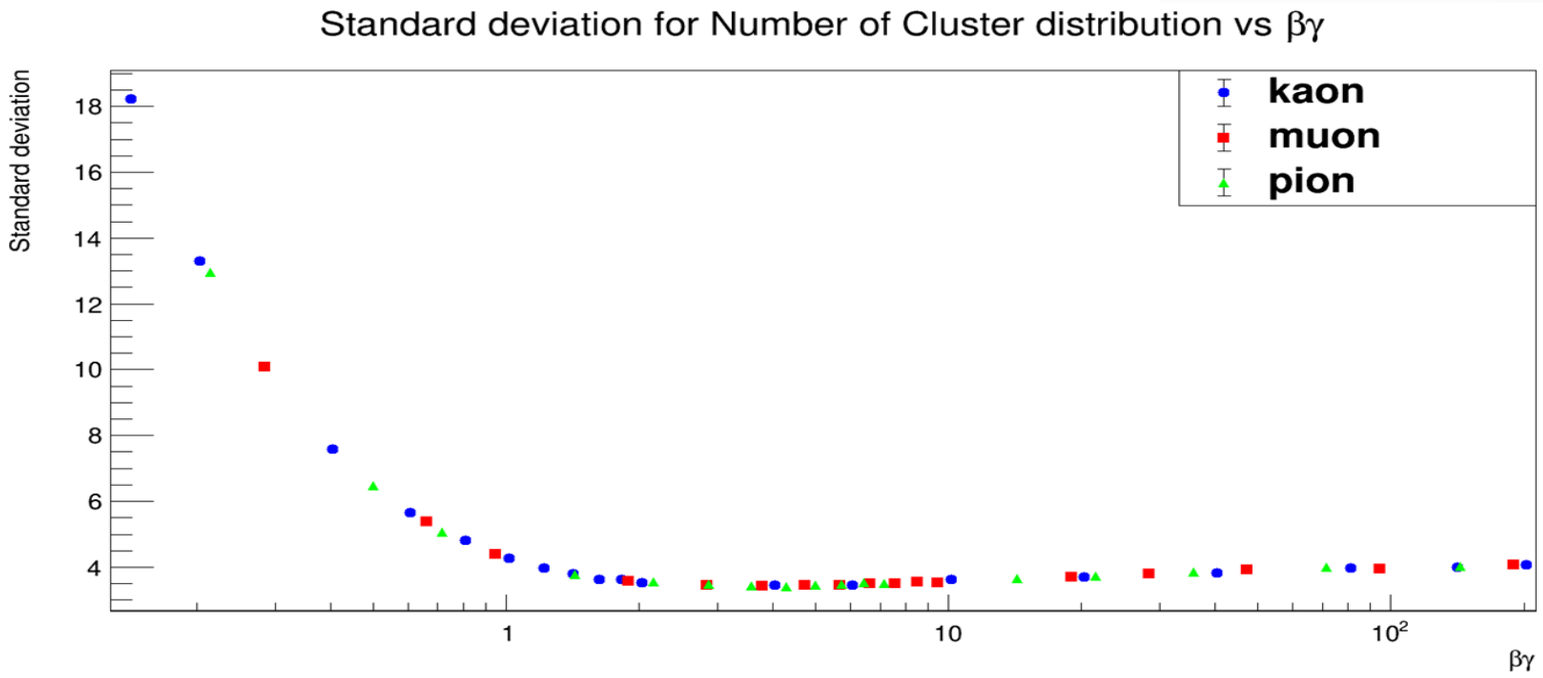


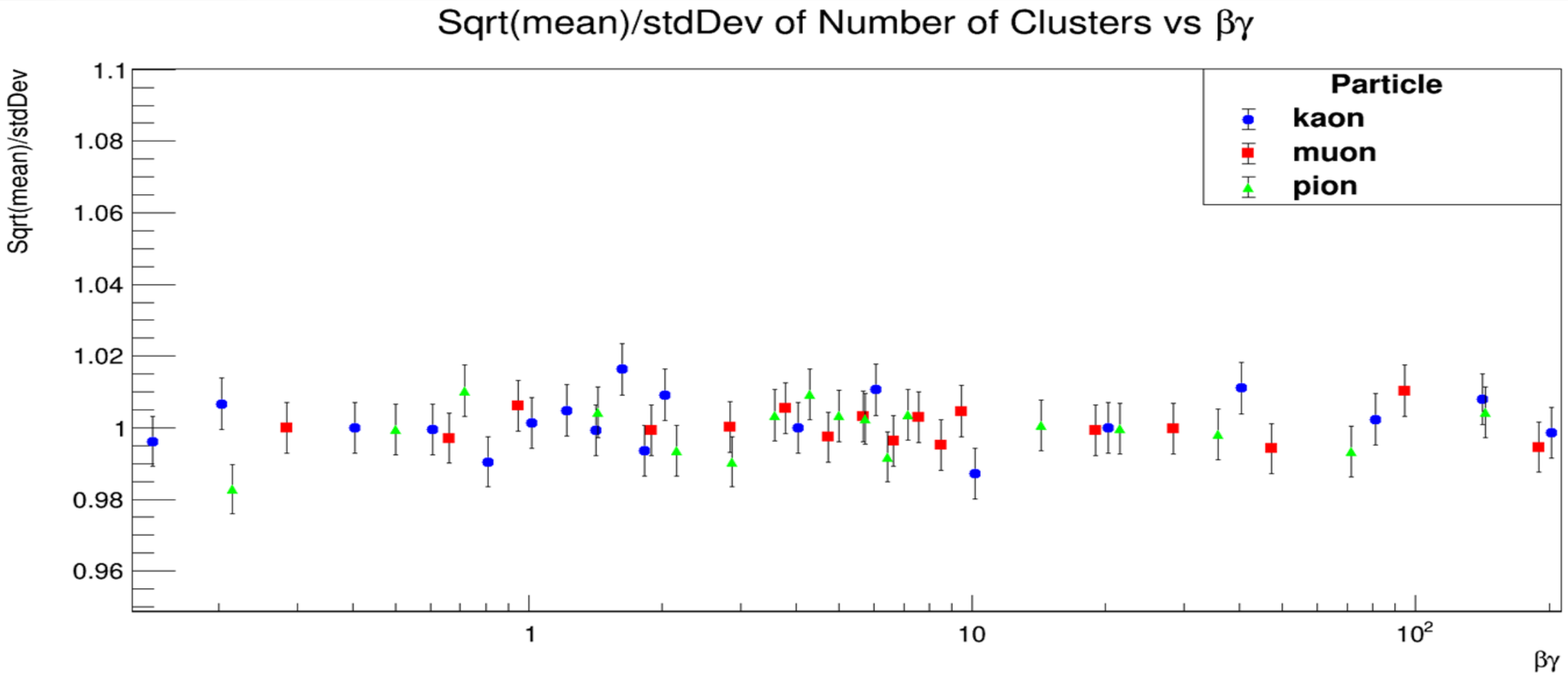


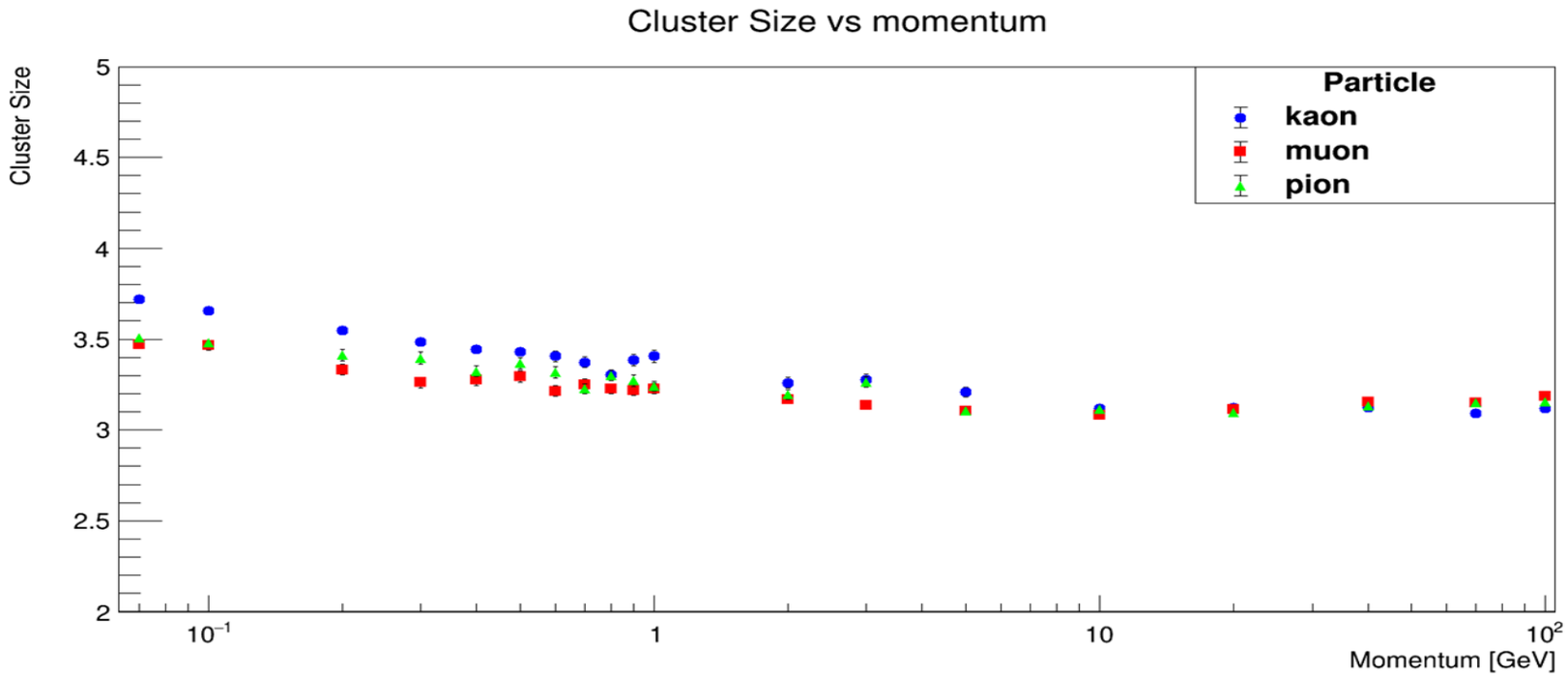

Number of cluster for different particles vs momentum
Number of Cluster
Momentum [GeV]
Particle
kaon
muon
pion

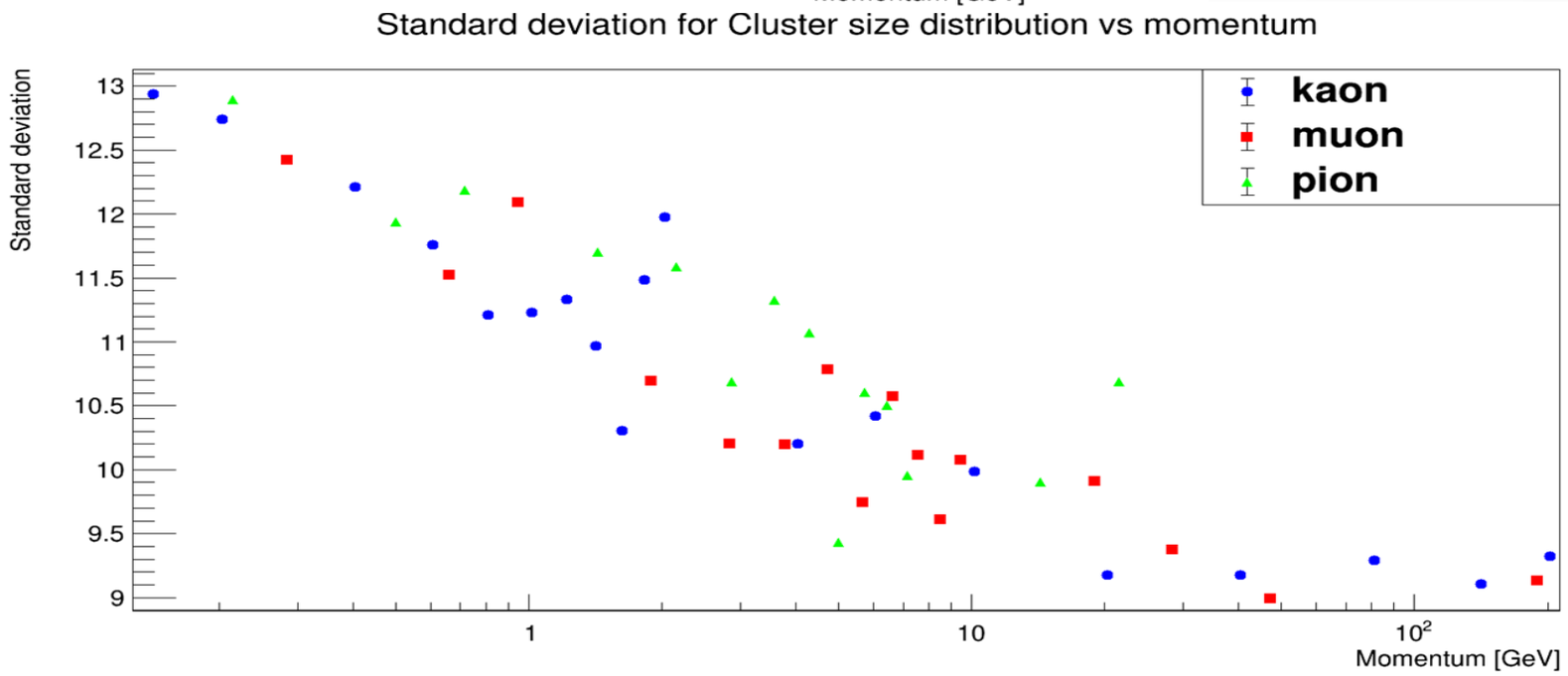

Standard deviation for Number of Cluster distribution vs momentum
Standard deviation
Momentum [GeV]
Particle
kaon
muon
pion

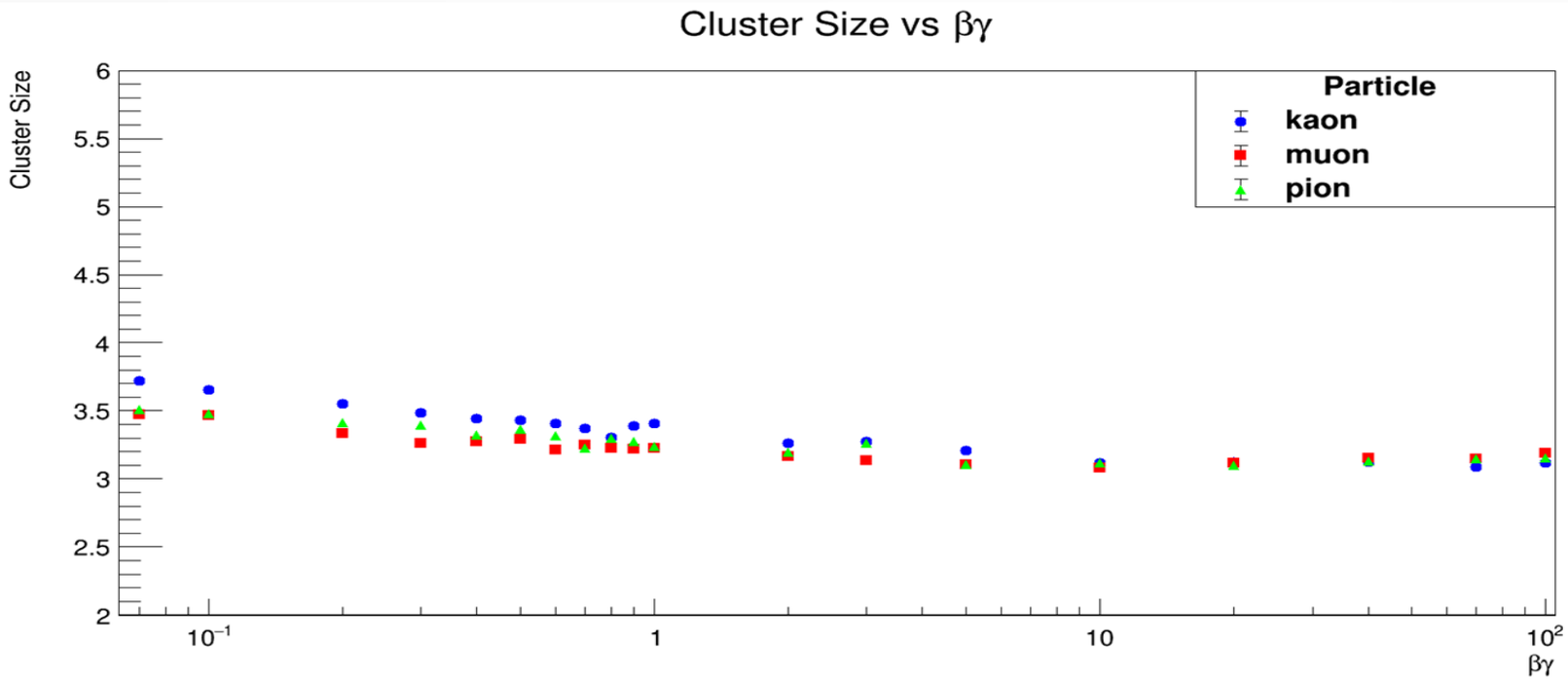

Number of cluster for different particles vs βγ
Number of Cluster
600
500
400
300
200
100
0
1
10
10²
βγ
Particle
kaon
muon
pion

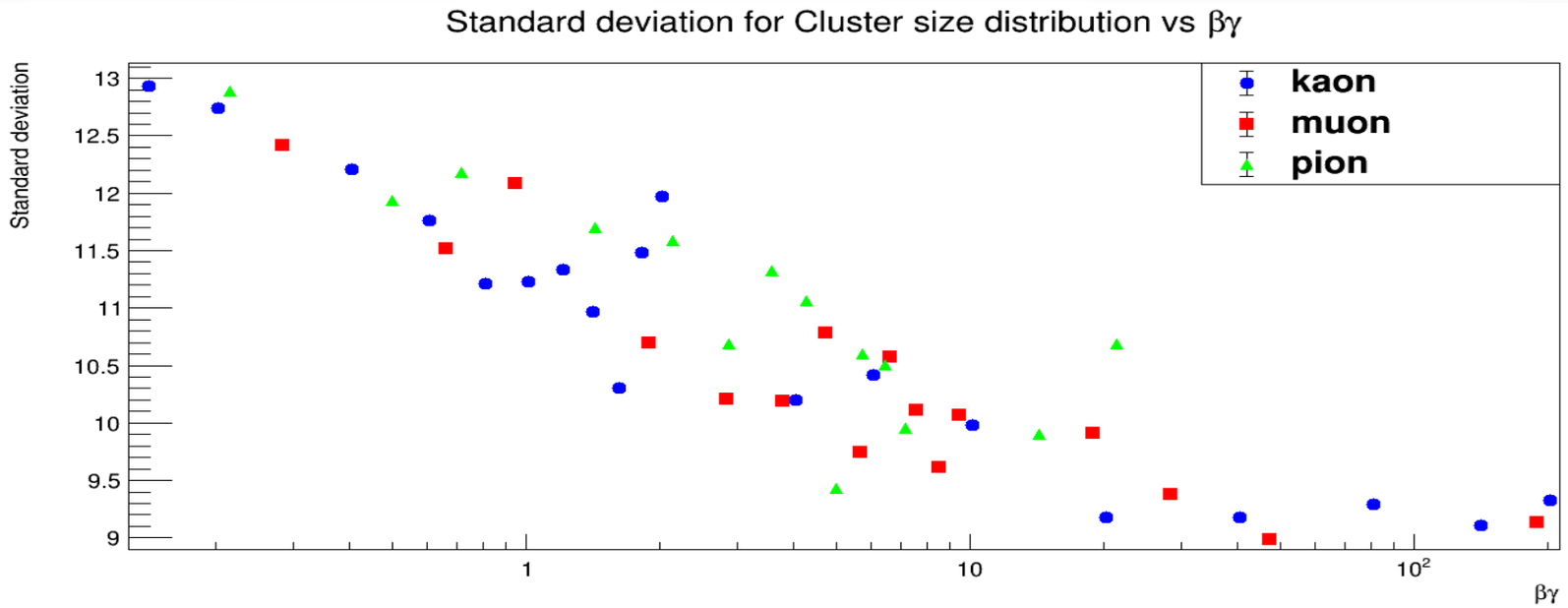

Standard deviation for Number of Cluster distribution vs βγ
Standard deviation
18
16
14
12
10
8
6
4
1
10
10²
βγ
kaon
muon
pion


Sqrt(mean)/stdDev of Number of Clusters vs βγ
Sqrt(mean)/stdDev
1.1
1.08
1.06
1.04
1.02
1
0.98
0.96
1
10
10²
βγ
Particle
kaon
muon
pion


Cluster Size vs momentum
Cluster Size
Momentum [GeV]
Particle
kaon
muon
pion


Standard deviation for Cluster size distribution vs momentum
Standard deviation
Momentum [GeV]
kaon
muon
pion


Cluster Size vs βγ
Cluster Size
βγ
Particle
kaon
muon
pion


Standard deviation for Cluster size distribution vs βγ
Standard deviation
βγ
kaon
muon
pion

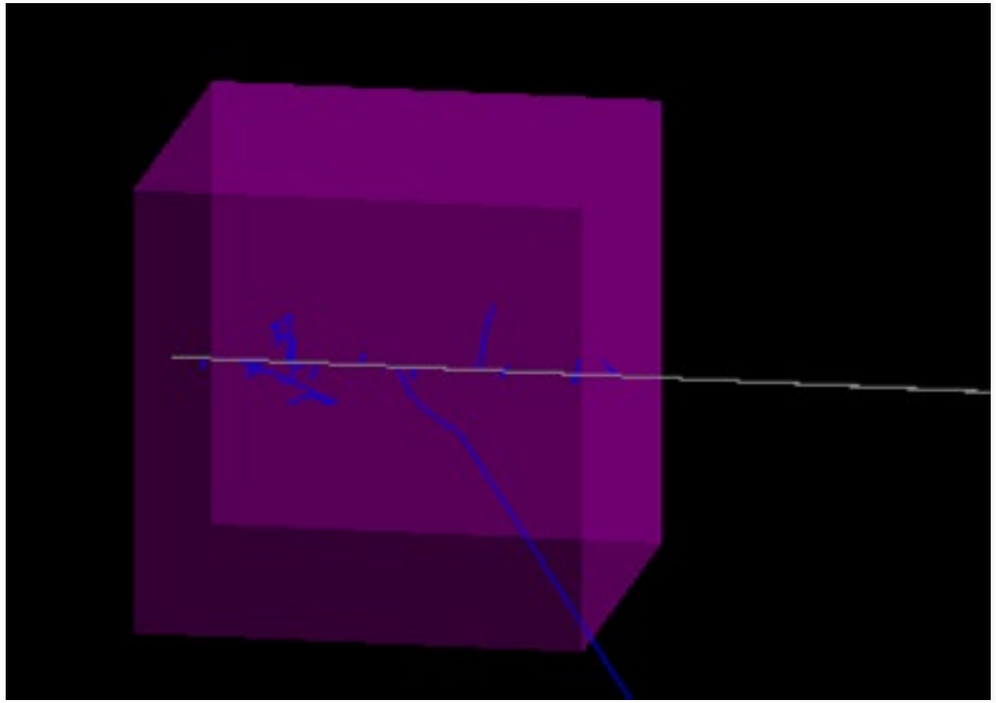
Details about Geant4 simulation

We are simulating the same gas box as in Garfield++ simulation.

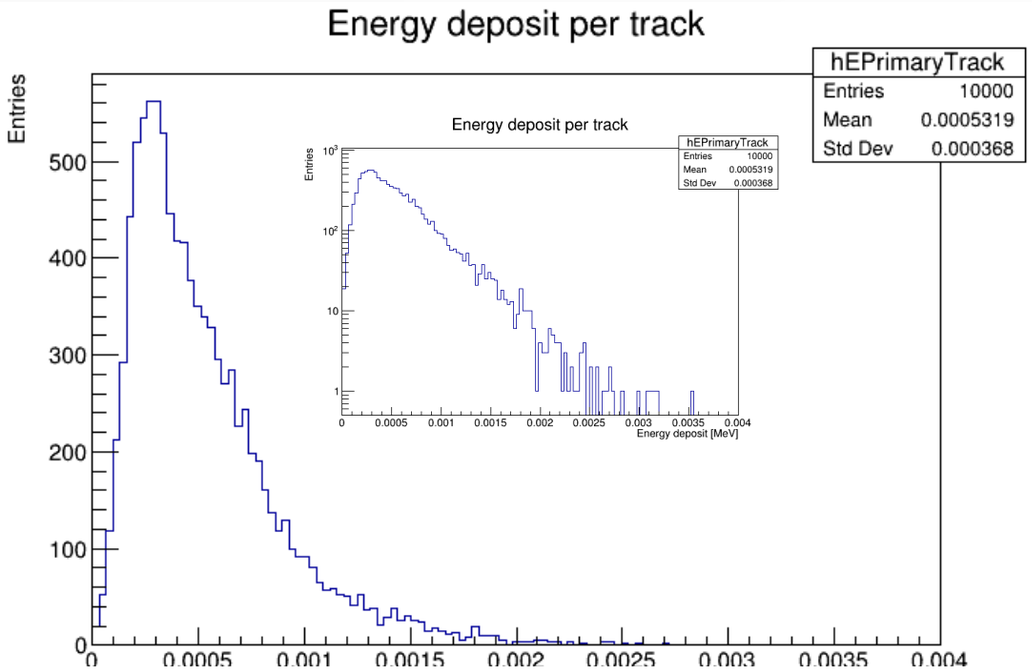
The physics list is "**QGSP_BERT**" with:

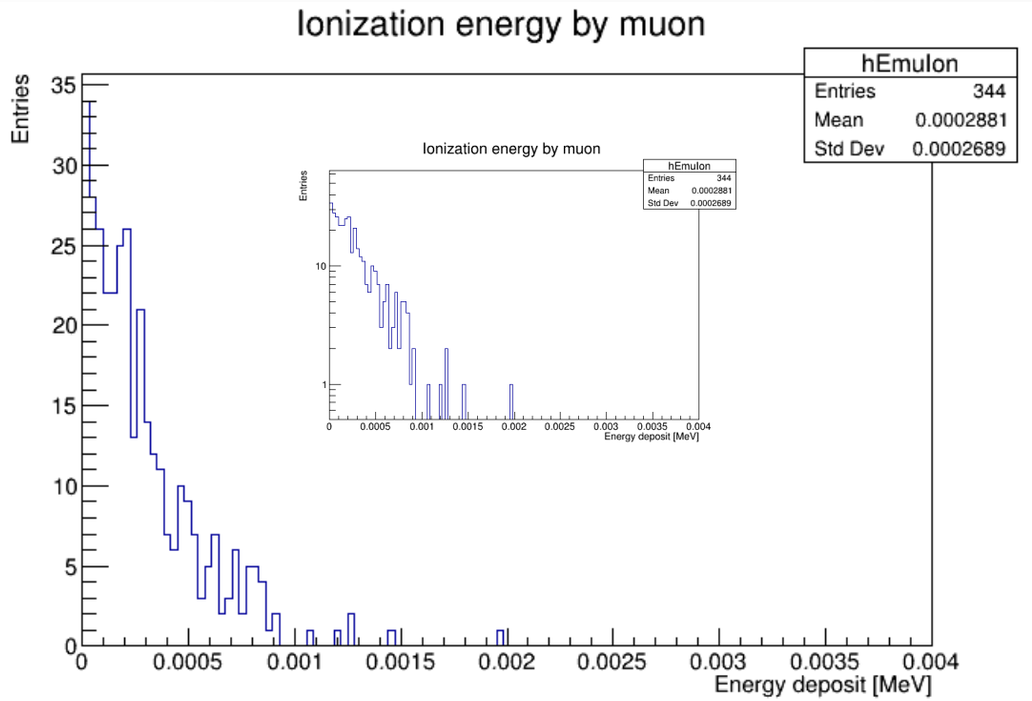
- G4EmStandardPhysics_option3()
- G4EmExtraPhysics()
- G4DecayPhysics()

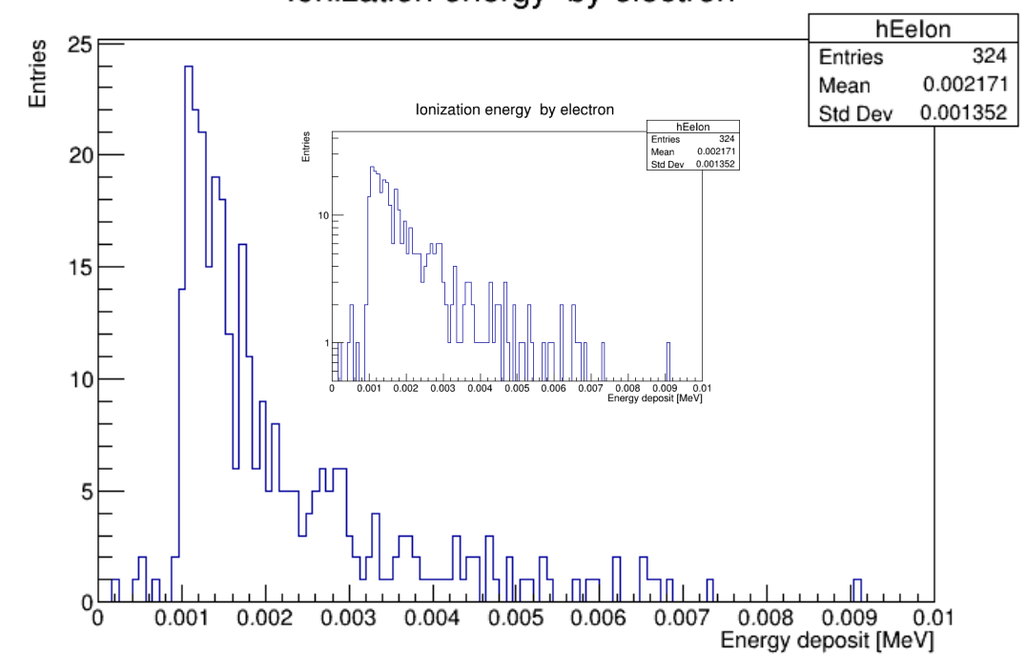
Actually we are investigating how to properly set *energy cuts*, by using **G4UserLimits** class.

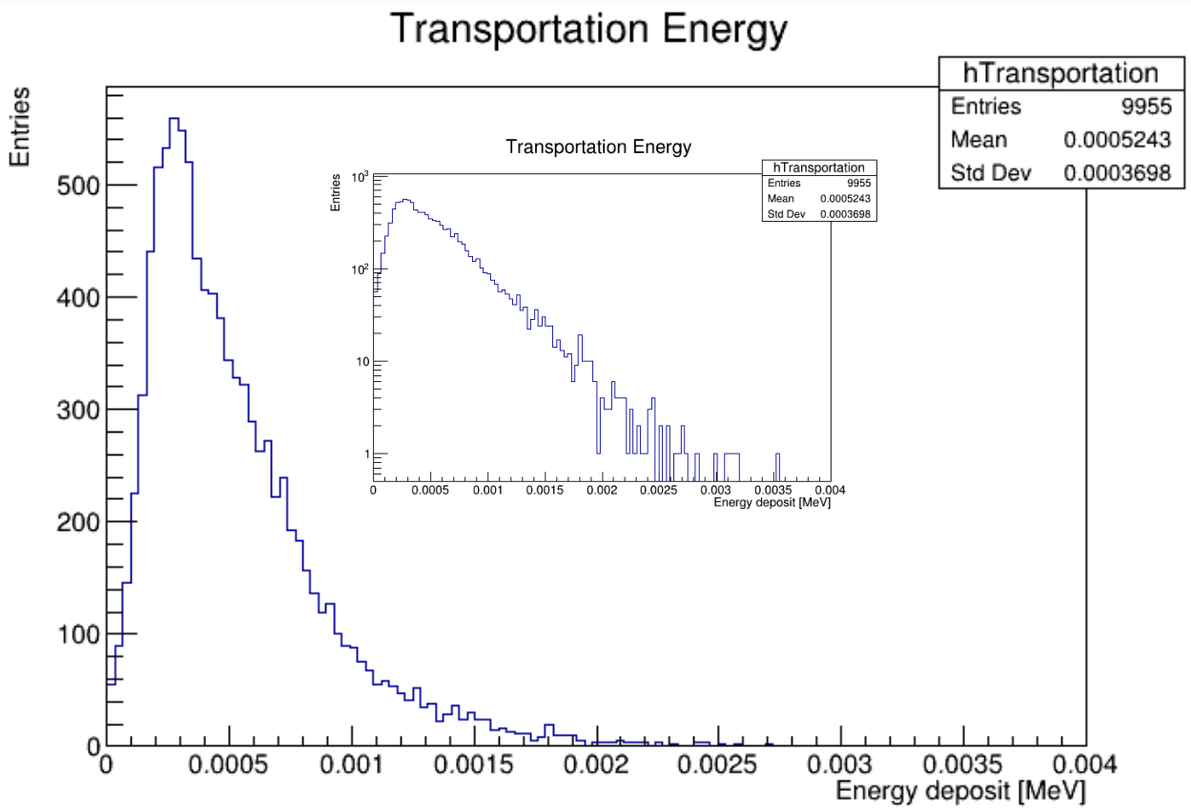


Next slides will show some results collected simulating 10000 events of a **mu-** with energy of **318 MeV**

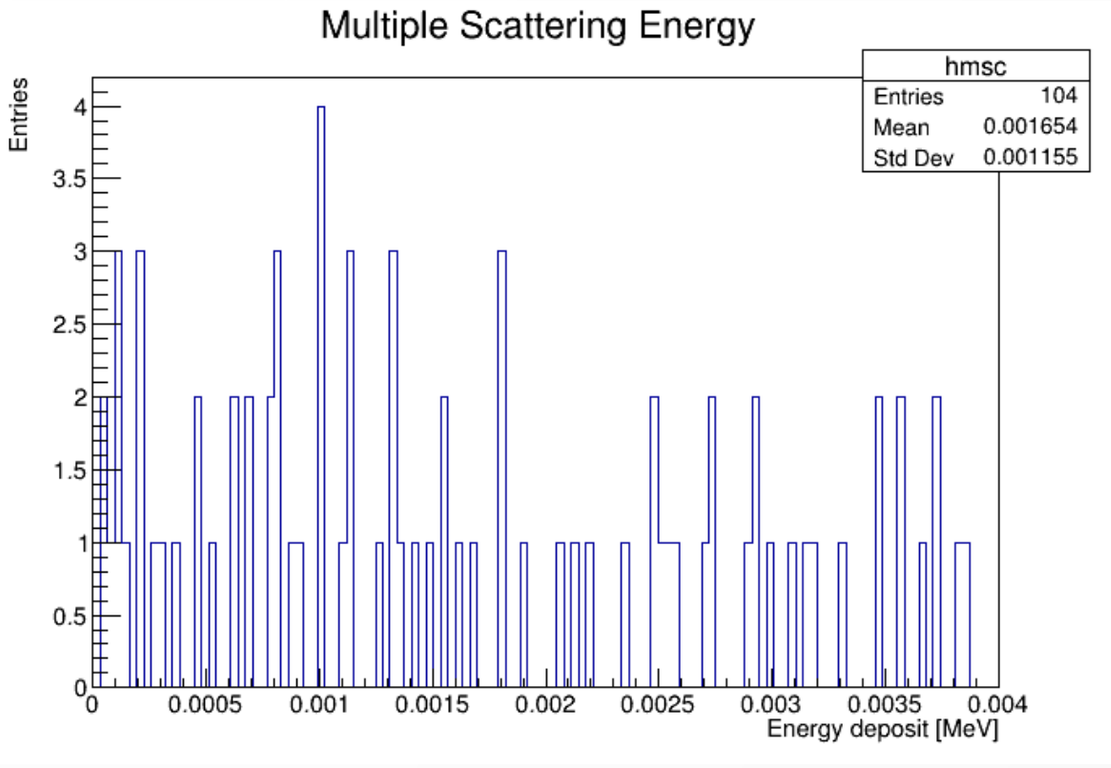

Energy deposit per track
hEPrimaryTrack
Entries 10000
Mean 0.0005319
Std Dev 0.000368
Entries
Energy deposit [MeV]


Ionization energy by muon
hEmuIon
Entries 344
Mean 0.0002881
Std Dev 0.0002689
Entries
Energy deposit [MeV]

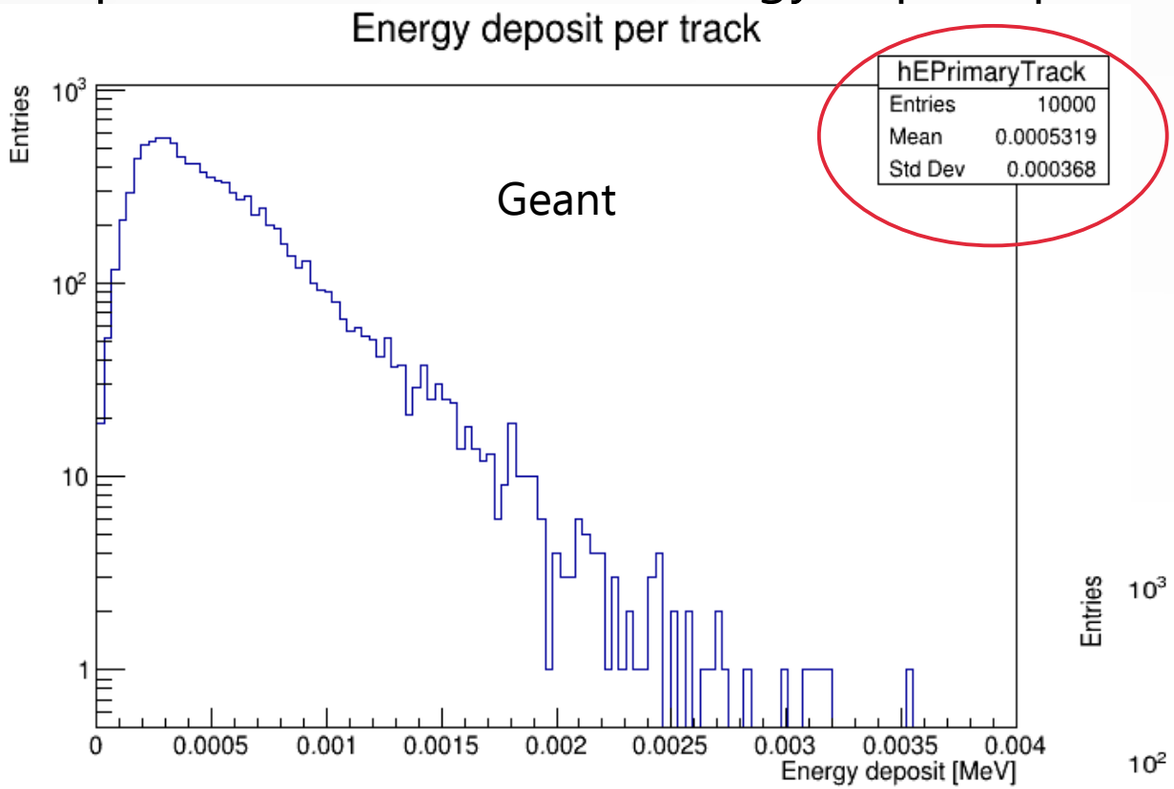

Ionization energy by electron
hEeIon
Entries 324
Mean 0.002171
Std Dev 0.001352
Entries
Energy deposit [MeV]



<<In all steps of a charged particle the ionisation process has what is called an "along step" action in Geant4 which deposits energy that corresponds to the energy of delta electrons which have been produced, but fall below the production threshold - this is standard practice in Type II particle transport algorithms (Berger).
The transportation process simply limits the step at a boundary in some steps, including the one which you observed.>>
John Apostolakis

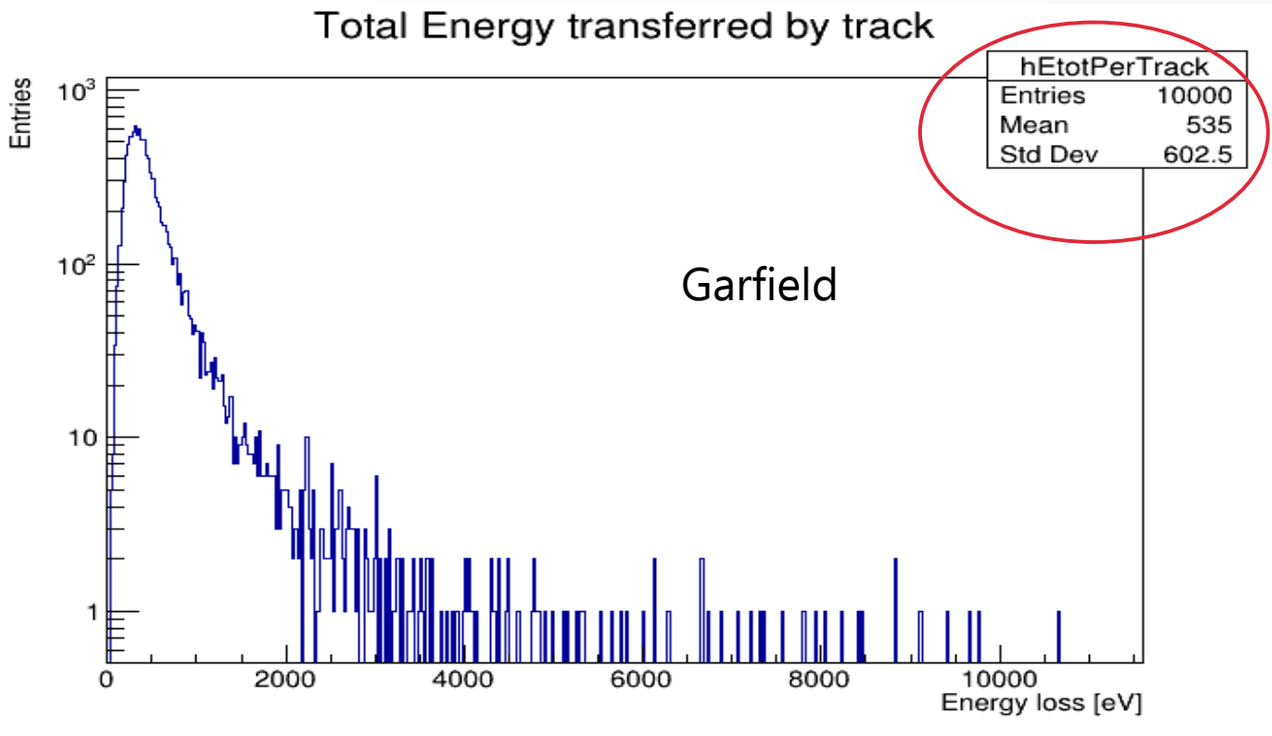


Comparison between total energy deposit per track

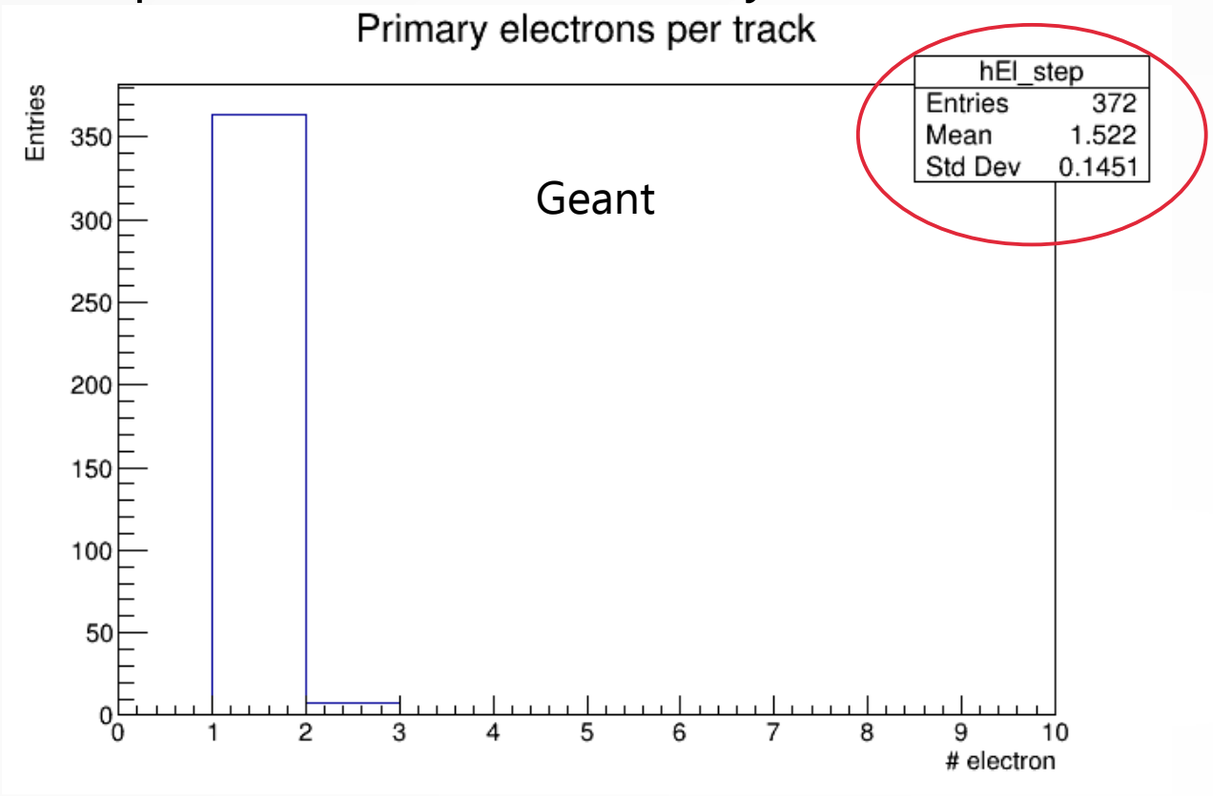


Mean 531 eV

Mean 535 eV

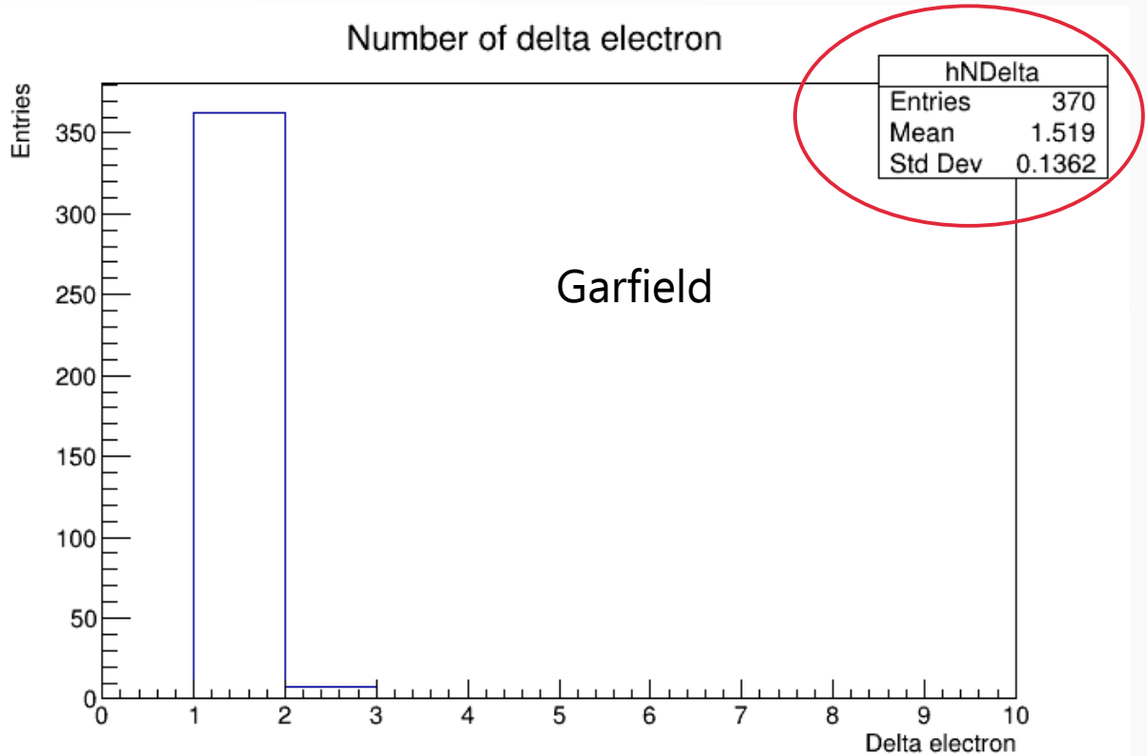


Comparison between delta rays

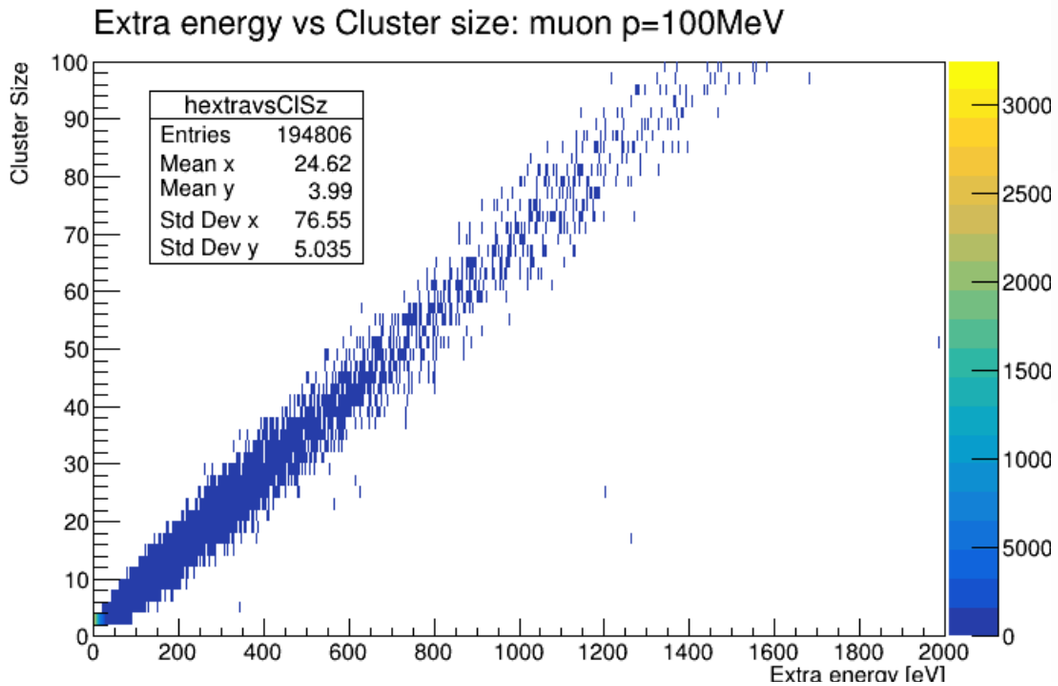


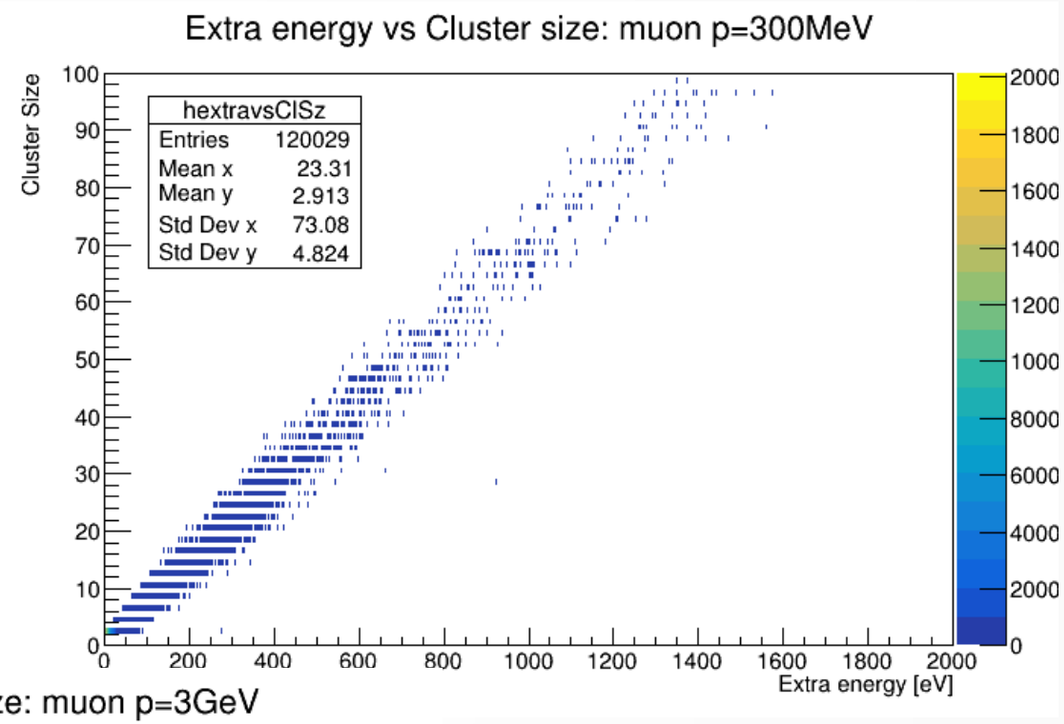
We empirically set a cut on number of electron obtained with Garfield simulation, selecting just the event with Cluster size higher than 70.

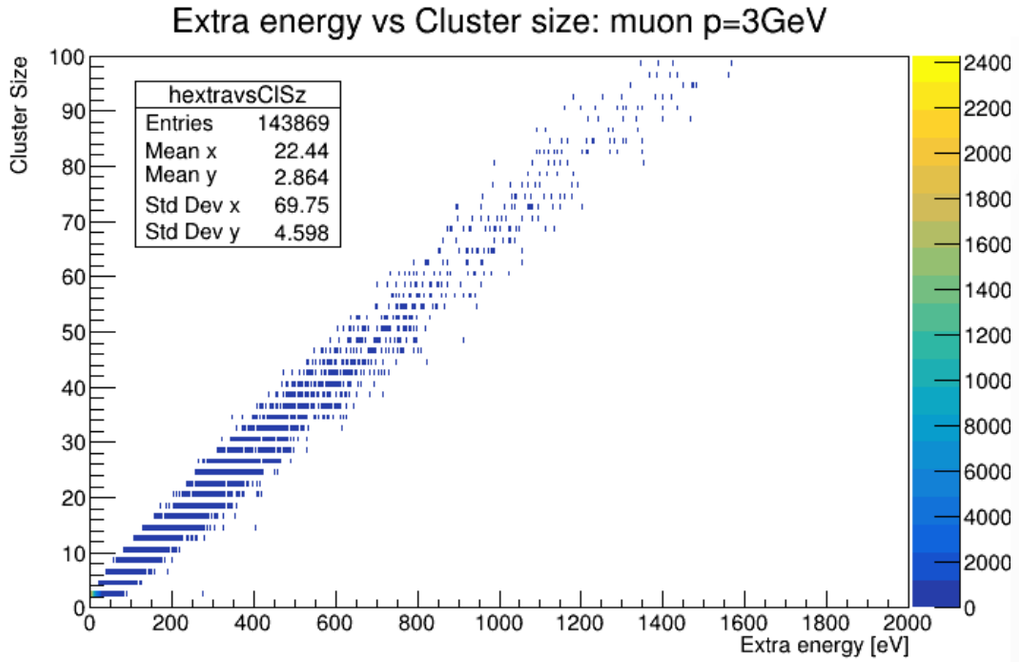
This could be an estimation of the number of delta rays produced during the interaction of mu- with our target

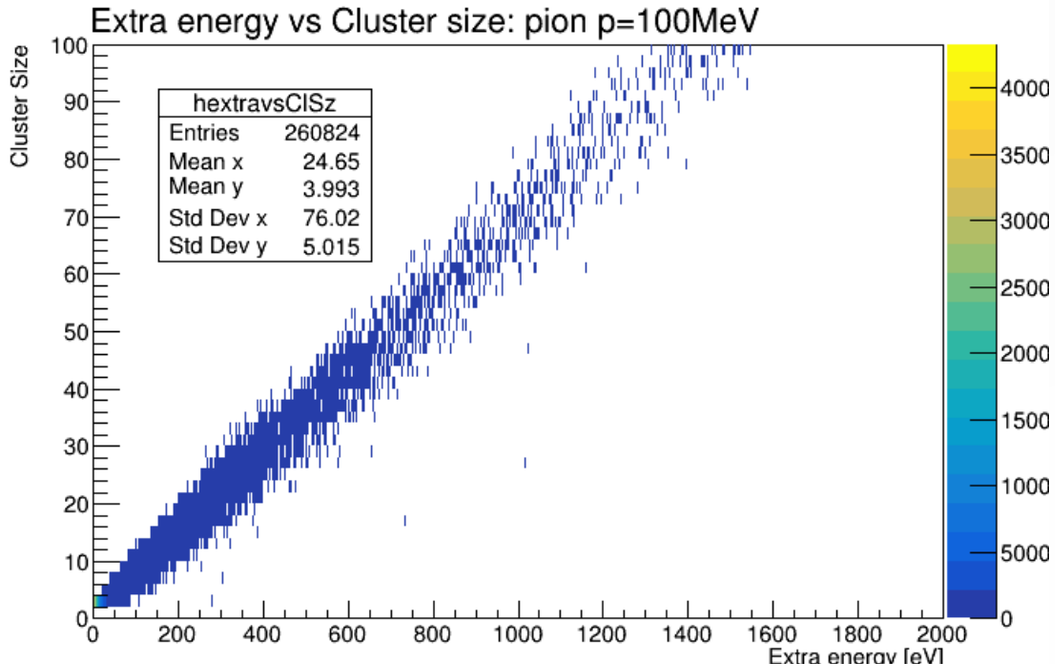


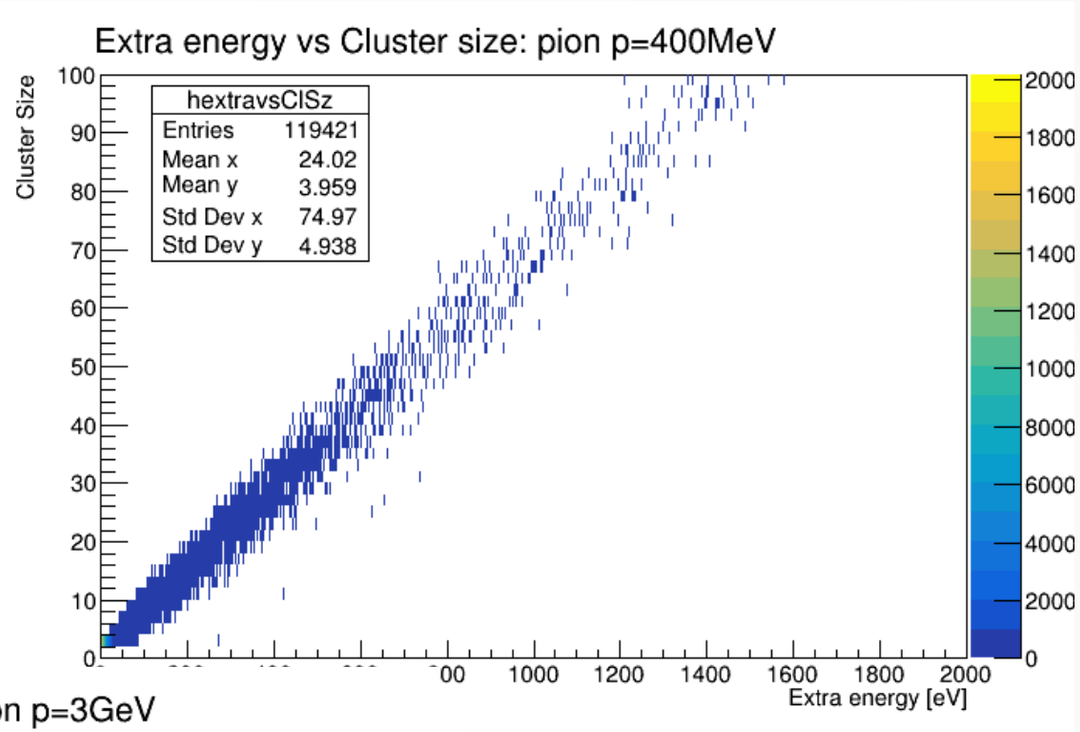
BACK-UP SLIDES

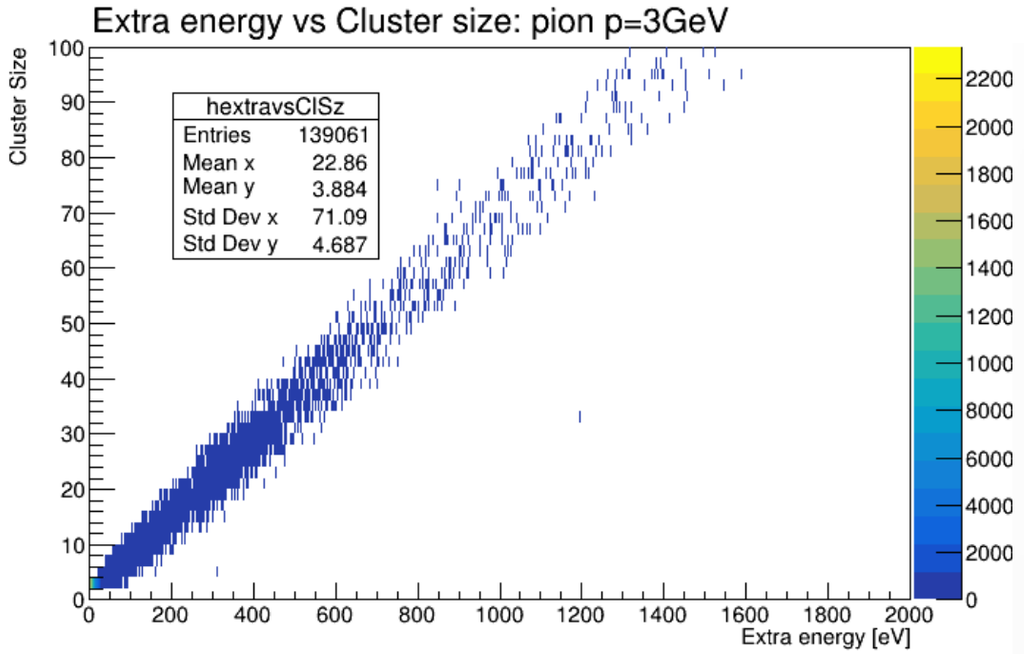

Extra energy vs Cluster size: muon p=100MeV
hextravsClSz
Entries 194806
Mean x 24.62
Mean y 3.99
Std Dev x 76.55
Std Dev y 5.035
Cluster Size
Extra energy [eV]

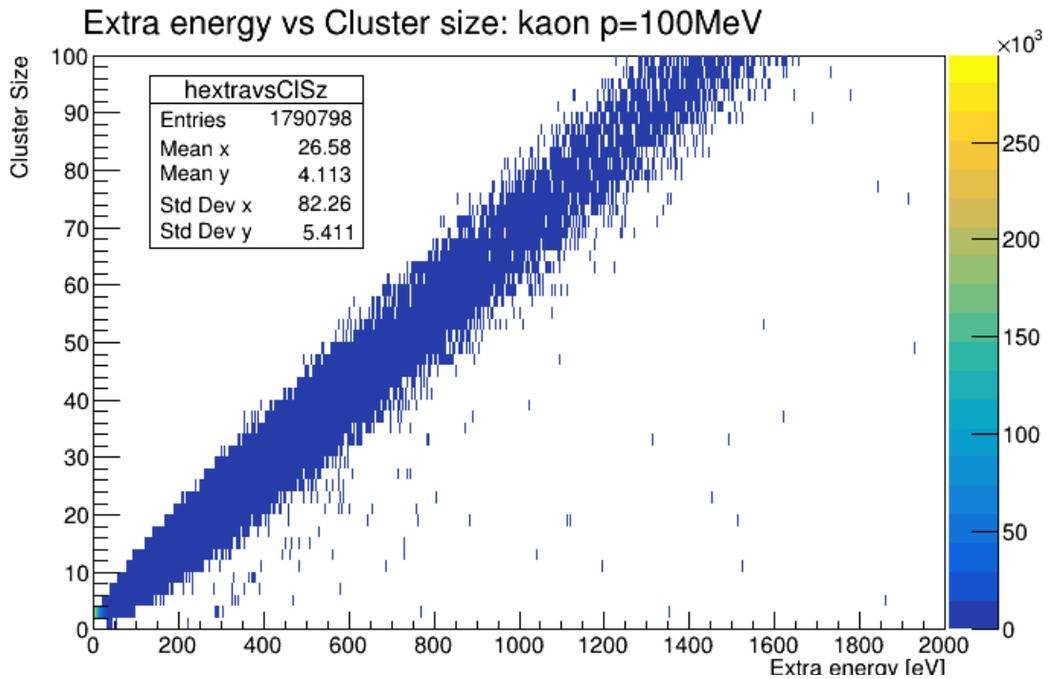

Extra energy vs Cluster size: muon p=300MeV
hextravsClSz
Entries 120029
Mean x 23.31
Mean y 2.913
Std Dev x 73.08
Std Dev y 4.824
Cluster Size
Extra energy [eV]

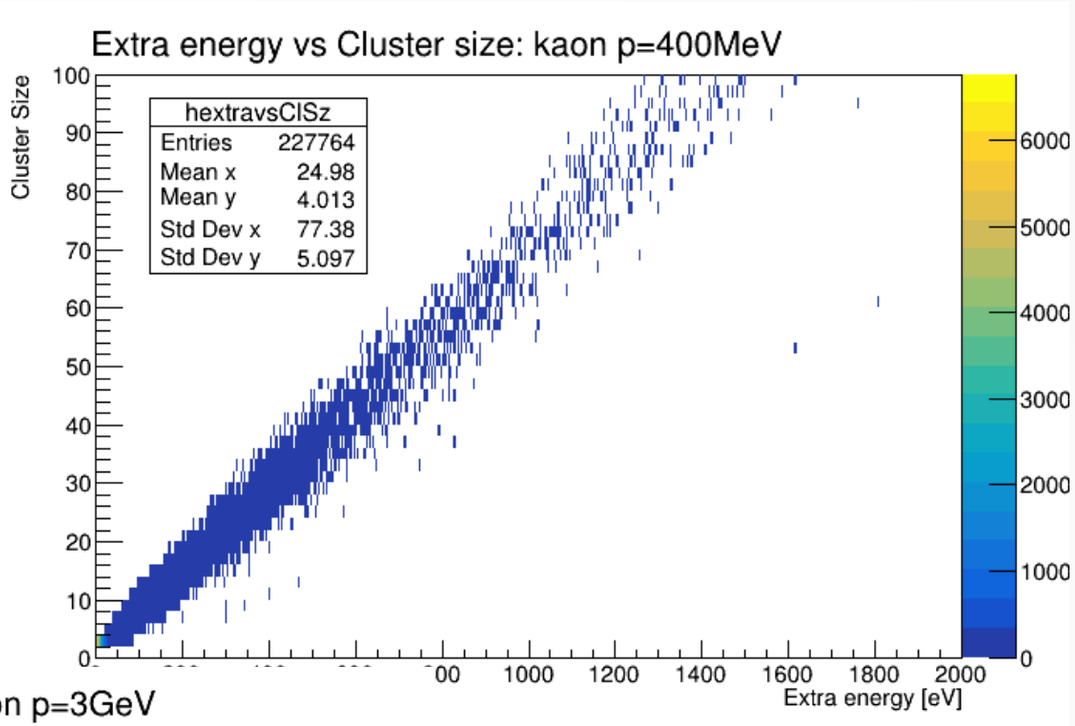

Extra energy vs Cluster size: muon p=3GeV
hextravsClSz
Entries 143869
Mean x 22.44
Mean y 2.864
Std Dev x 69.75
Std Dev y 4.598
Cluster Size
Extra energy [eV]

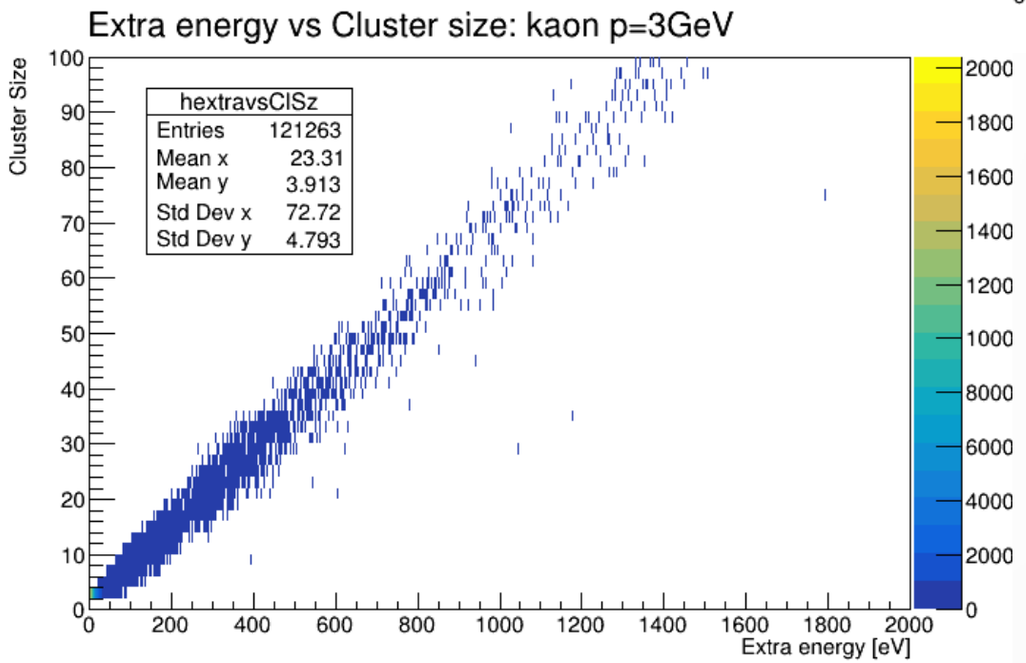

Extra energy vs Cluster size: pion p=100MeV
hextravsClSz
Entries 260824
Mean x 24.65
Mean y 3.993
Std Dev x 76.02
Std Dev y 5.015
Cluster Size
Extra energy [eV]


Extra energy vs Cluster size: pion p=400MeV
hextravsClSz
Entries 119421
Mean x 24.02
Mean y 3.959
Std Dev x 74.97
Std Dev y 4.938
Cluster Size
Extra energy [eV]


Extra energy vs Cluster size: pion p=3GeV
hextravsClSz
Entries 139061
Mean x 22.86
Mean y 3.884
Std Dev x 71.09
Std Dev y 4.687
Cluster Size
Extra energy [eV]


Extra energy vs Cluster size: kaon p=100MeV
hextravsClSz
Entries 1790798
Mean x 26.58
Mean y 4.113
Std Dev x 82.26
Std Dev y 5.411
Cluster Size
Extra energy [eV]
×10³


Extra energy vs Cluster size: kaon p=400MeV
hextravsClSz
Entries 227764
Mean x 24.98
Mean y 4.013
Std Dev x 77.38
Std Dev y 5.097
Cluster Size
Extra energy [eV]


Extra energy vs Cluster size: kaon p=3GeV
hextravsClSz
Entries 121263
Mean x 23.31
Mean y 3.913
Std Dev x 72.72
Std Dev y 4.793
Cluster Size
Extra energy [eV]